

Advances of multi kHz picosecond laser systems for SLR

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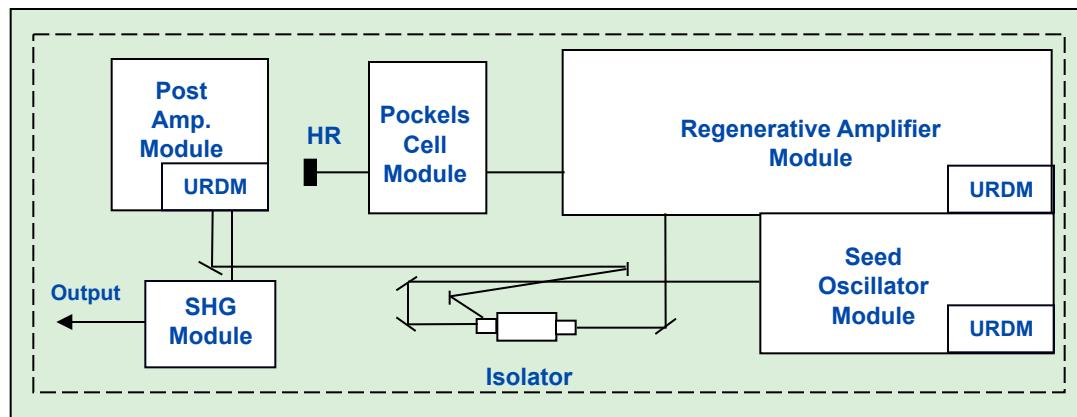
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Austria
www.highQlaser.at

HIGH LASER® *
Think Ultrafast!™

What is the goal of an ultra fast laser system?

- Generate short pulses: ca. 10ps
- Amplification to high energies (~mJ) at high repetition rates (~kHz)
- Conversion to visible: Blue 435nm; Green, 527/532nm
- High power stability: < 1% RMS
- High pulse-to-pulse stability: <1% RMS
- Beam quality: $M^2 < 1.5$
- Robust and compact overall system

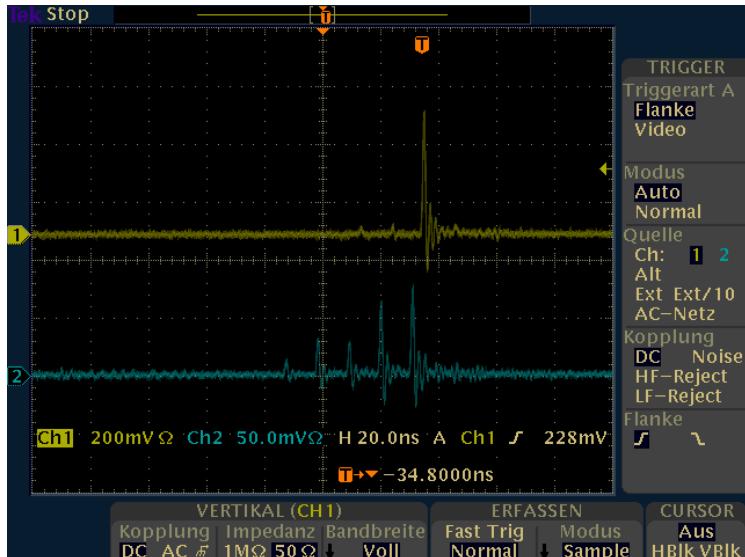
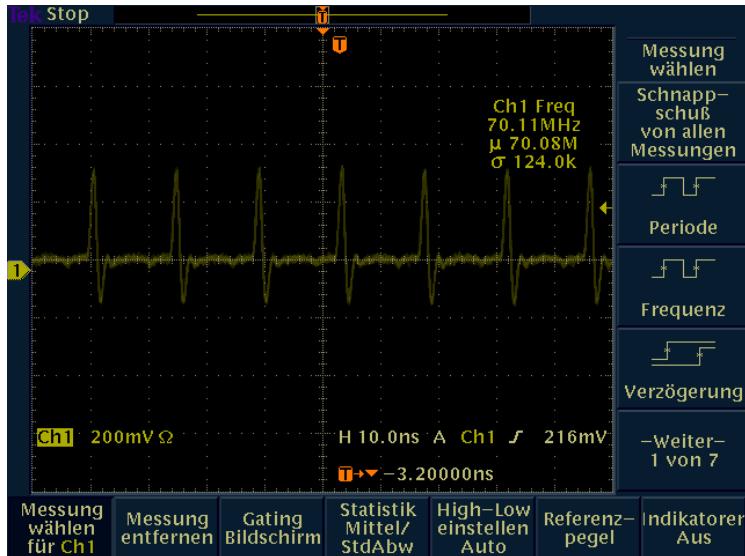
picoREGEN: Picosecond diode pumped oscillator / regenerative amplifier / post amplifier laser system

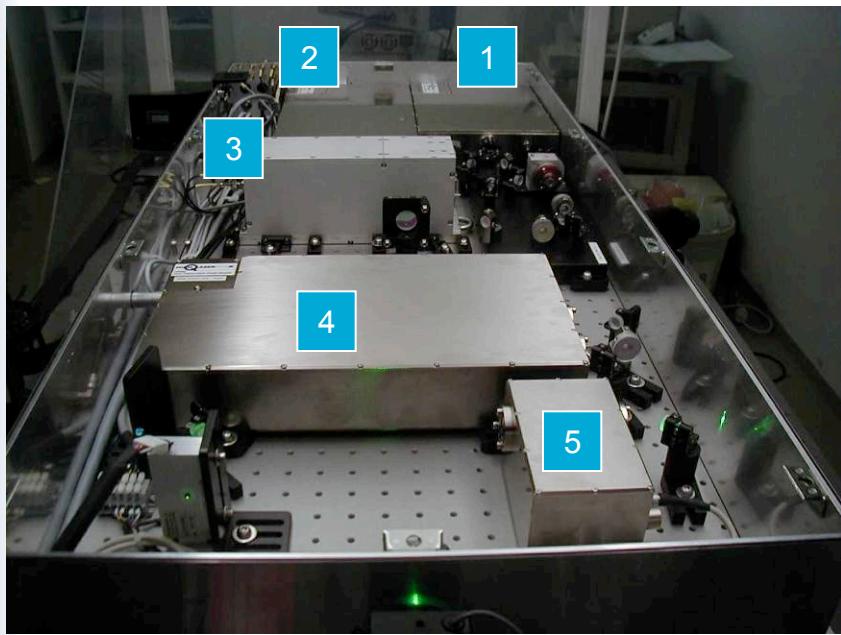


- Wavelength 1064nm internal/532nm
- Pulse duration 12ps
- Average power max. 0.8W
- Pulse energy 0.5mJ@1kHz; 0.4mJ@2kHz
- Repetition rate single pulse to 2kHz
- Robust, monolithic, all-in-one system, no external pump lasers

REGEN – Pulse Generation and Amplification

- First the ultra short pulse is generated
 - Seed laser oscillator signal
- Then it is amplified in a regenerative amplifier
 - REGEN output laser pulse and internal build up signal

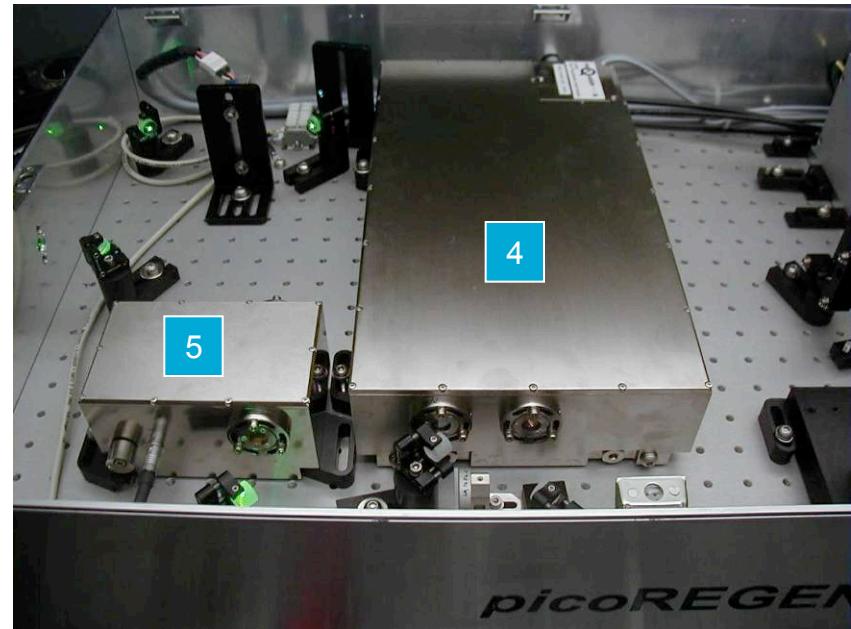




Strictly modular set-up:

1. Seeder
2. Regenerative amplifier
3. Pockels – cell
4. Post-amplifier
5. SHG module

Post-amplifier and SHG module

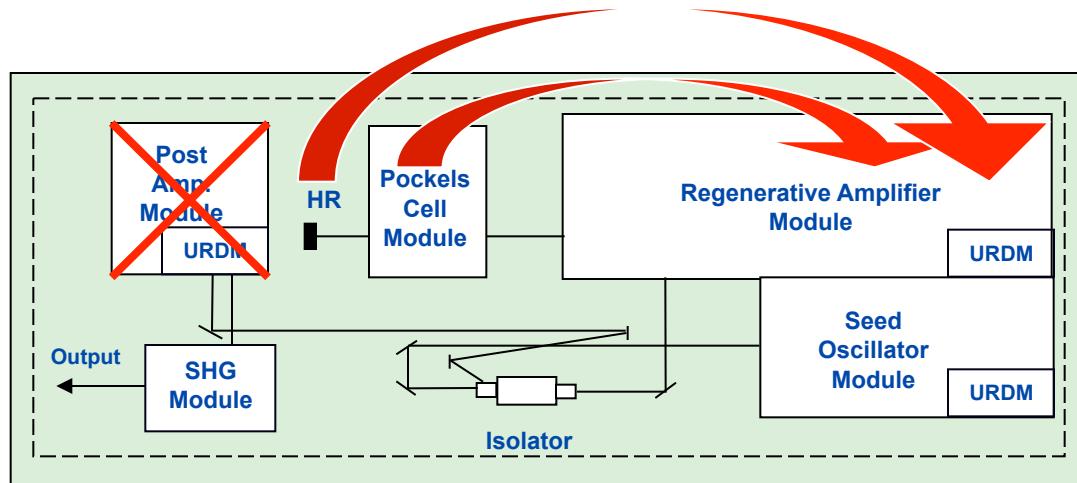


New input from application side: Higher Pulse Energy

- Scientists input: Higher pulse energy
>3mJ@1kHz and **>1.5mJ@2kHz** in IR
(1.2mJ@1kHz; 0.6mJ@2kHz in VIS)
- But: Limitation from laser material Nd:VAN
 - Laser state life time: ca. 200µs
 - Single pass gain: 2-3
 - REGEN + post amplifier
- Change of laser material to Nd:YLF
 - Laser state life time: ca. 550µs
 - Single pass gain: 1.5
 - REGEN only concept

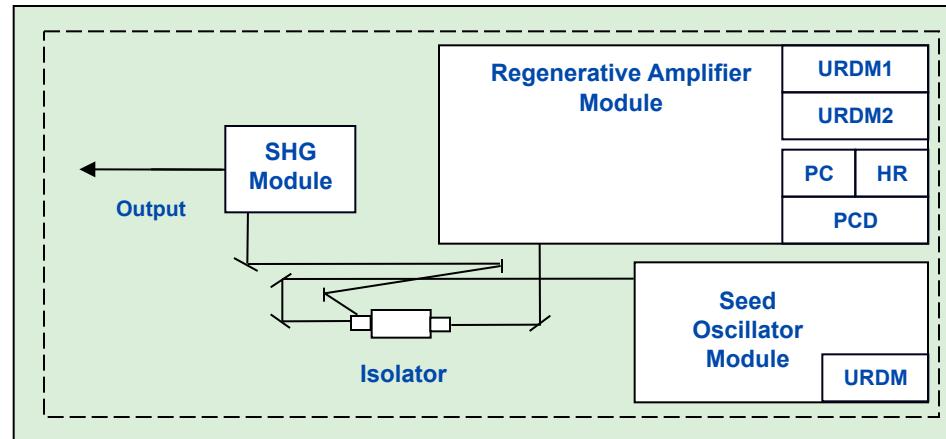
Reducing system complexity

picoREGEN: Picosecond diode pumped oscillator / regenerative amplifier / post amplifier laser system



- Avoiding post amplification module due to higher laser state life time = energy storage capability
- Mechanical integration of end mirror (HR) into REGEN module
- Mechanical integration of Pockels cell module into REGEN module

picoREGEN: Picosecond diode pumped oscillator / regenerative amplifier laser system



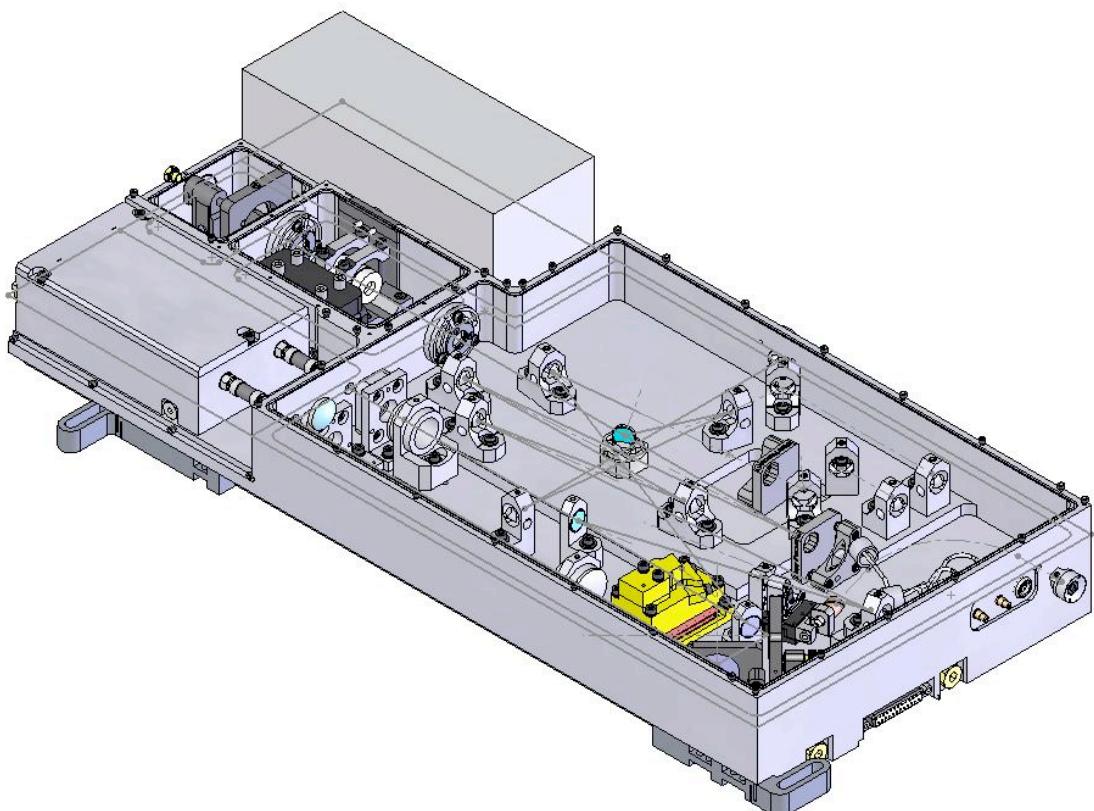
- Wavelength 1053nm internal/527nm
- Pulse duration 8ps
- Average power 1.2W
- Pulse energy 1.2mJ@1kHz (2.4x increase);
0.6mJ@2kHz
- Repetition rate single pulse to 2kHz, optional to 50kHz
- Robust, monolithic, all-in-one system, no external pump lasers

Advances of the new IC-527-1200

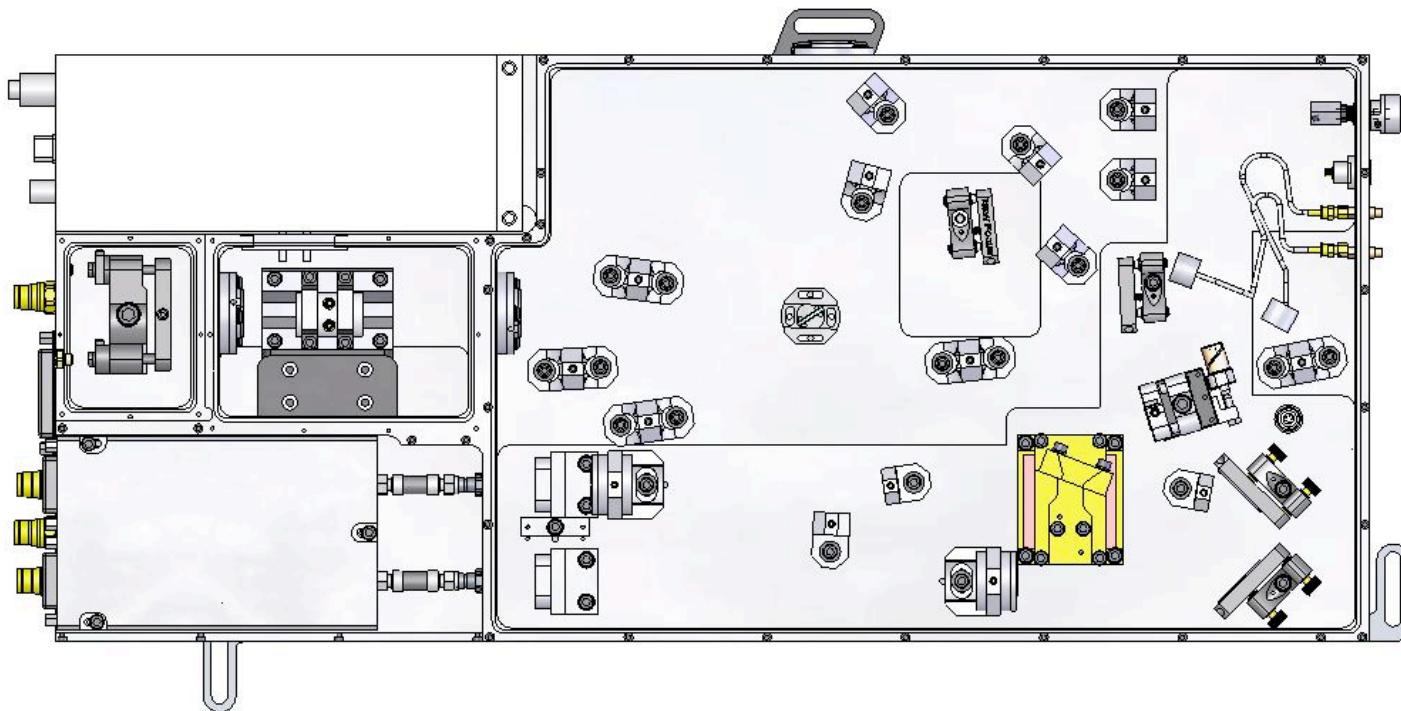
- No post amp (Nd:VAN 532nm → Nd:YLF 527nm)
- End mirror HR integrated in REGEN module → no realignment
- Pockels cell integrated
- Pockels cell driver integrated, can be exchanged without optical realignment
- Two fiber coupled URDMs (30W, 805nm) → Easy exchange
- Higher repetition rate:
 - up to 2kHz: Pulsed pumping, 650μs
 - 2kHz to 50kHz: CW pumping

REGEN module 3D view

- Monolithic set-up
- 20mm massive aluminum base plate / temp. stabilized
- Sealed-off enclosure
- Class 100 clean room manufactured

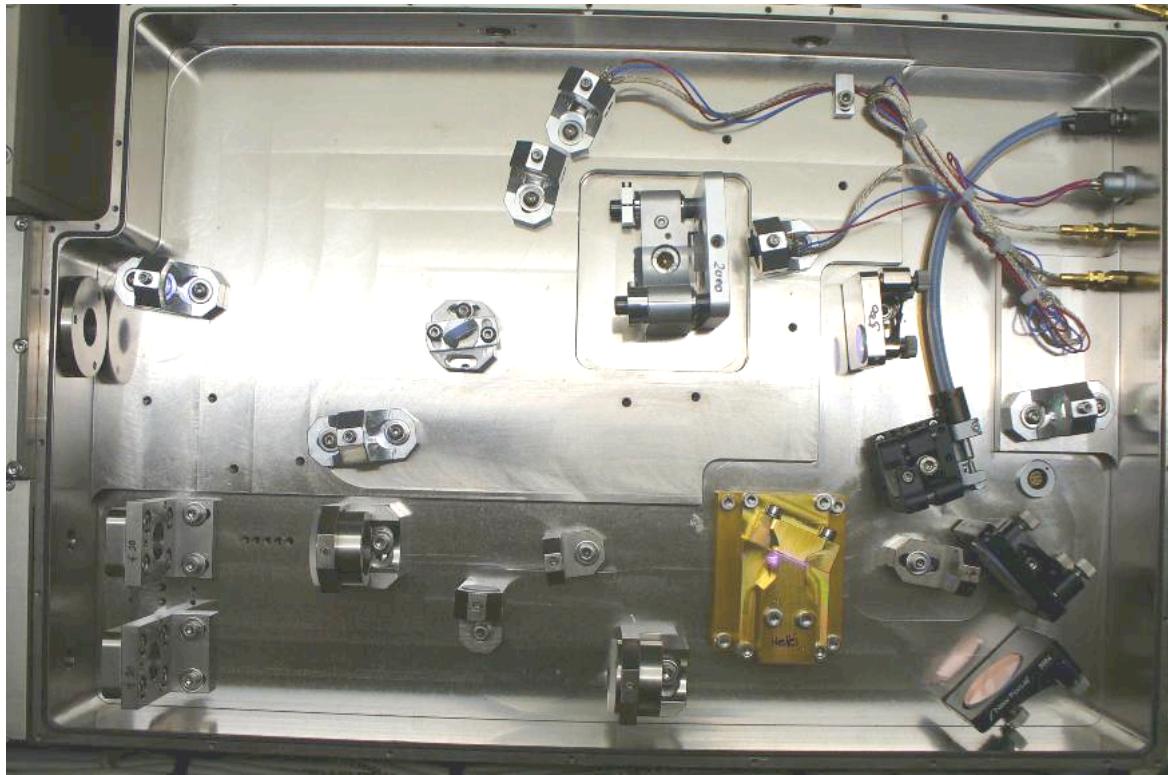


REGEN module top view



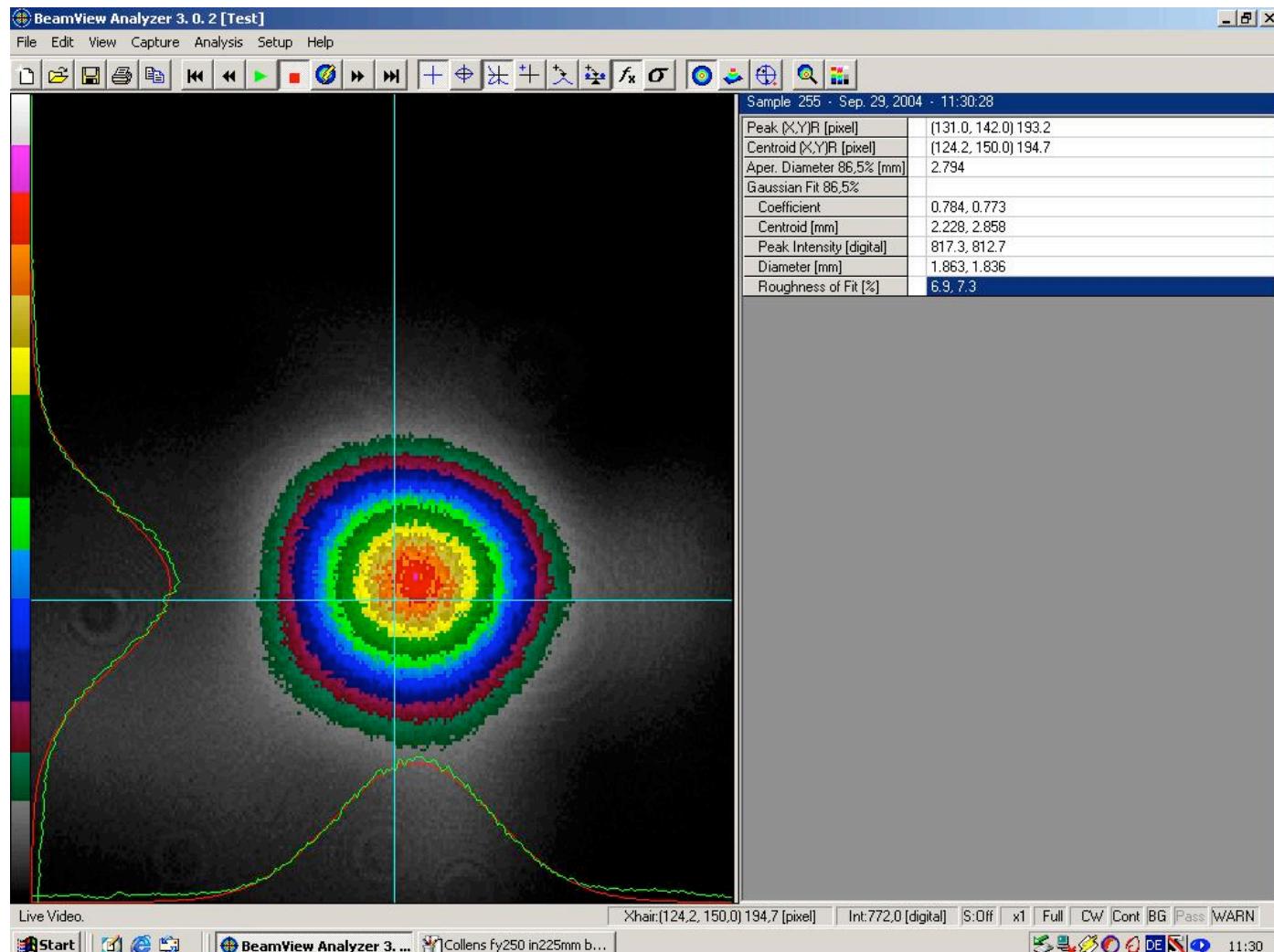
- FEA optimized industrial mirror mounts
- Access to end mirror and Pockels cell
- Improved laser crystal mount
- Double sided diode pumping

REGEN module top view (real 3D)

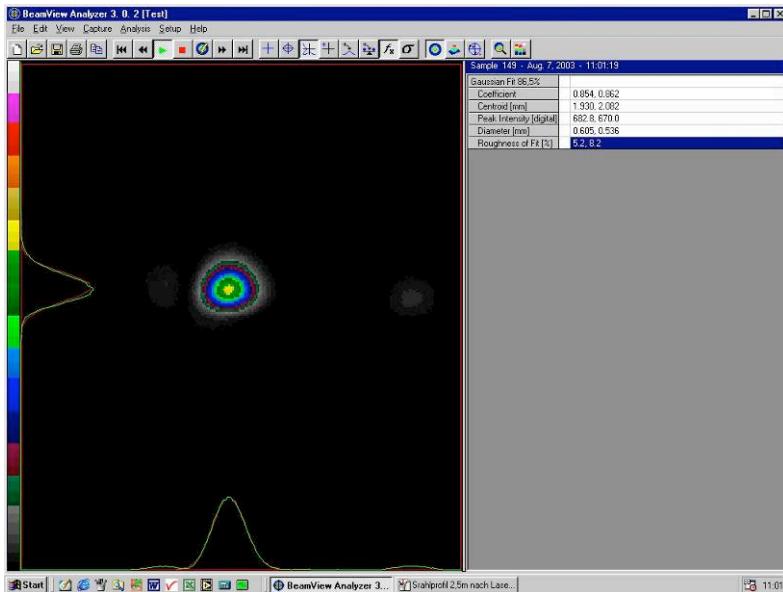


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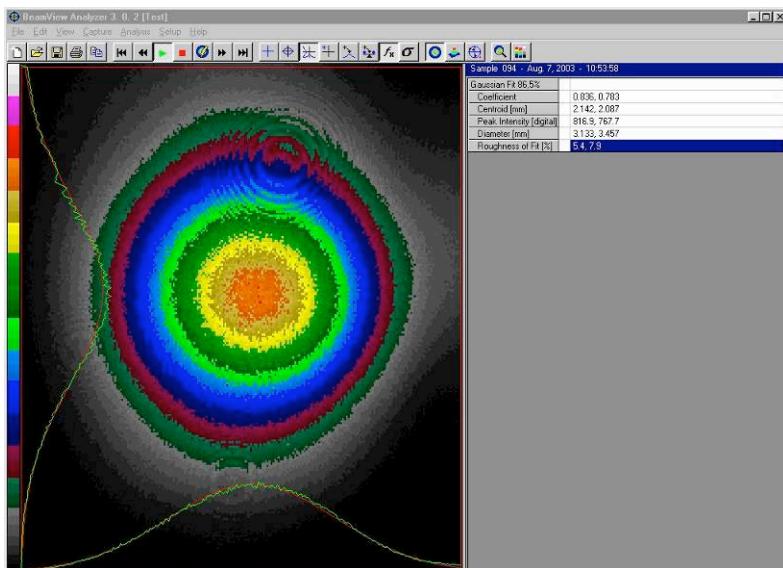
picoREGEN™ IR beam profile



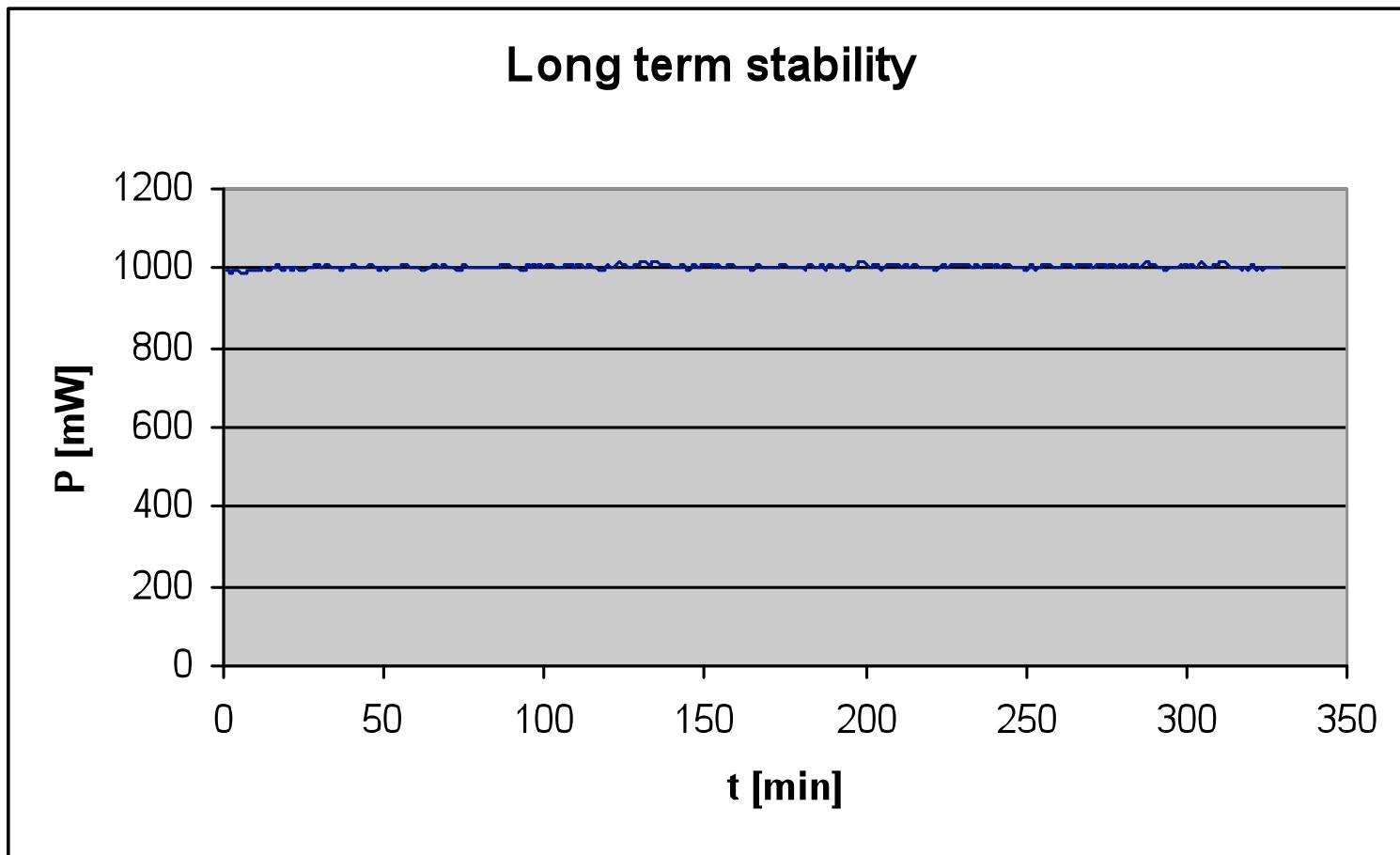
picoREGEN – SHG Beam Profile



- At Laser exit (GREEN)

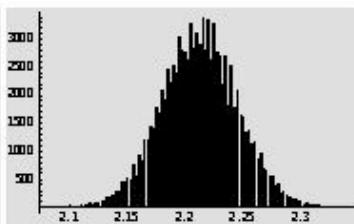
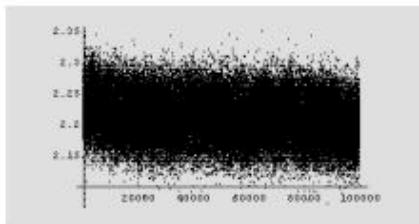


- 2500 mm after exit (GREEN)
- Divergence 0.64 mrad; half angle
- $M^2 < 1.5$



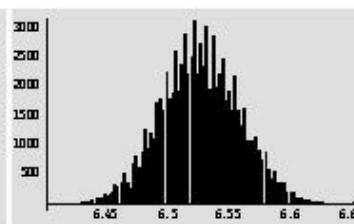
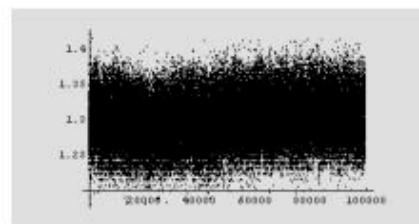
**532 nm, Power = 1000 mW, 2 kHz; RMS = 0,54%;
measured over 350 min = 5,8 h**

Pulse-to-Pulse stability in IR, SHG, THG, over 100000 shots



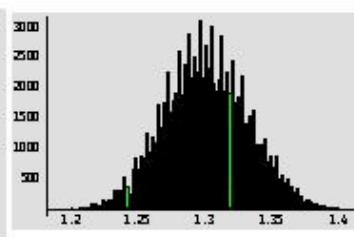
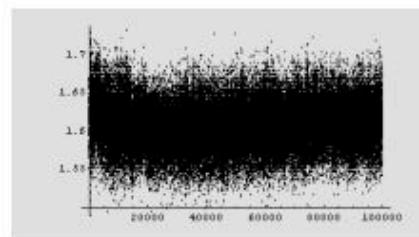
output @ 1047 nm
 $\sigma/\langle N \rangle \cong 0.0038$

IR: $\sigma < 0.4 \%$



output @ 523 nm
 $\sigma/\langle N \rangle \cong 0.0046$

SHG: $\sigma < 0.5 \%$



output @ 349 nm
 $\sigma/\langle N \rangle \cong 0.0094$

THG: $\sigma < 1 \%$

**Pulse Energy (a.u.)
vs. Pulse Number
(from 1 to 100000)**

histograms

picoREGEN™ UC-INDUSTRIAL



All-in-One Picosecond
Regenerative Amplifiers

picoREGEN™ SCIENCE



Different UC-models

UC-10000 HP	10 W	s.p. - 500
kHz, 20 µJ		
UC-30000 HP	30 W	s.p. - 500
kHz, 60 µJ		
→ TTL Trigger		
→ Nd:Vanadate		

Different SCIENCE models

SC-527-1200 SLR	0 – 2(50) kHz, 1.2 mJ;
SC-1053-3000 HE	0 – 2(50) kHz, 3.0 mJ
SC-1064-2000 TTL	5 or 10 kHz, >0.3 mJ
SC-1064-2000 HR	1 – 100(500) kHz, 0.3 mJ

High Q Laser - Product Groups

TRAIN Serie: Diode pumped ultrafast solid state oscillators

picoTRAIN™: 5 – 100 ps, 266 – 1342 nm, 8 – 1500 MHz, up to 25 W

femtoTRAIN™: 50 – 400 fs, 800 – 1070 nm, 50 – 120 MHz, up to 5 W

NOVA Serie: Cavity-Dumped Mode-locked ultrafast oscillators

femtoNOVA™: Up to 1 µJ, single pulse to 1 MHz TTL trigger

picoNOVA™: Up to 1 µJ, single pulse to 1 MHz TTL trigger

REGEN Serie: All-in-one ultrafast regenerative Amplifier

picoREGEN™: 8 - 18 ps, 1047 – 1064 nm, up to 500 kHz, up to 30 W, up to 3 mJ

femtoREGEN™: 350 – 650 fs, 1030 – 1053 nm, up to 500 kHz, up to 8 W, up to 1 mJ

ps-Ti:Sapphire oscillators and amplifier:

High power oscillators up to 20 W

Regenerative fs/ps amplifiers with up to 500 kHz rep rate

Cavity dumped MHz-laser-system:

Up to 1 MHz / up to 1 μ J / ps- and fs- pulses

Burst-mode regenerative amplifier:

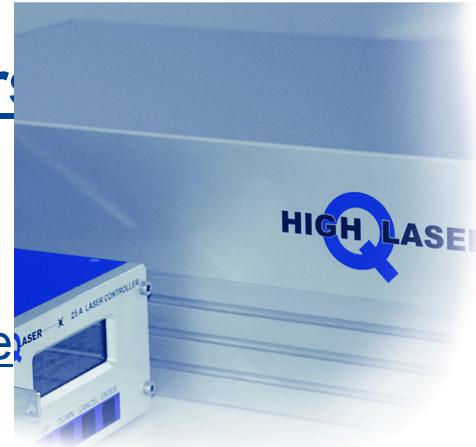
1.06 um / 1 kHz burst operation / 10 pulses per burst / 4 mJ per burst / 10 ps pulses

946 nm / 473 nm picosecond laser

1.34-um picosecond laser:

1.34 um / 3 W / 15 ps pulses

ps-OPO (for CARS-microscopy):



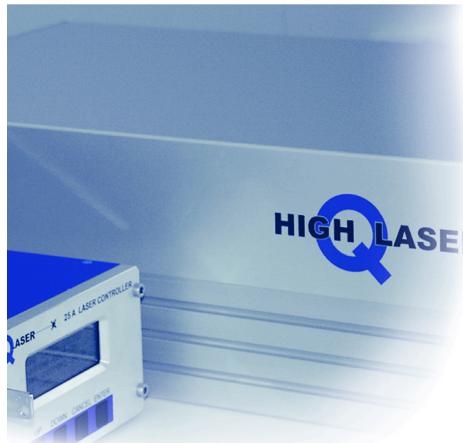
SYNC Option

**all-electrical repetition rate synchronization
pulse jitter < 0.5 ps (RMS)
pulse repetition rate 50 – 400 MHz**



Electro-optical pulse selection module „Pulse Picker“

Cavity Dumping Module: 1 µJ @ 1 MHz for TRAIN series



Long Pulse Option

SHG, THG, FHG

Customized reprise: down to 8 MHz, up to 1500 MHz, variable Repetition Rate

High Q Laser – company overview

- **Founded 1999**, privately owned and financed
- Specialized in development, manufacturing and distribution of ultra short diode pumped solid state laser (DPSSL) systems
- **Headquarter** at Hohenems (by lake Constance)/Austria
- **International strong Team** of about ~45 specialists and academics
- More than 300 installed lasers Systems worldwide
- **Class 100 clean room** manufacturing
- More than 60 scientific **publications**
- **Main Markets** are Research , Medical, Imaging, Nanoprocessing, Semiconductor
- **Subsidiary** (100%) for Sales and Service in **Masachusetts/USA**; Worldwide distribution and service network

- **Strong Team**
- **Compact Design**
- **Modular Concept**
- **Innovative R&D**
- **OEM Experience**

Thank you ...



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HIGH LASER® *
Think Ultrafast!™

Your Personal Contact for Further Information



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Optical Spectrum



Frequency Spectrum



Time Behavior



Beam Profile



Autocorrelation



Power Meter

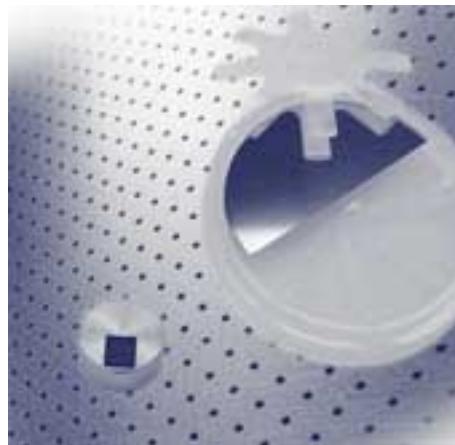


Direct diode-pumping + SESAMs

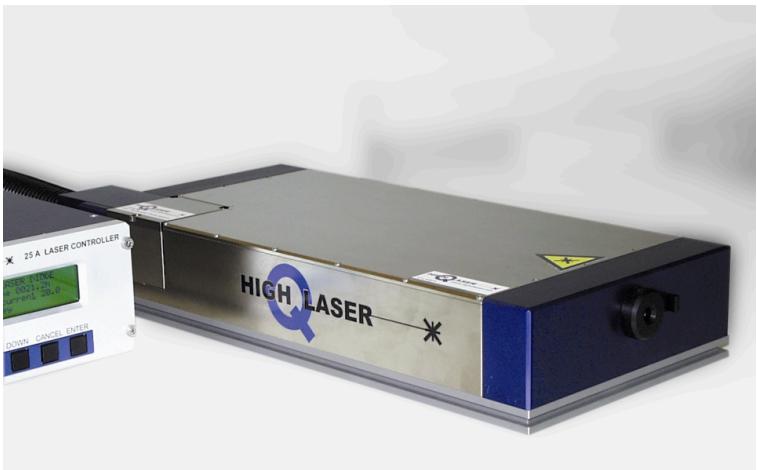


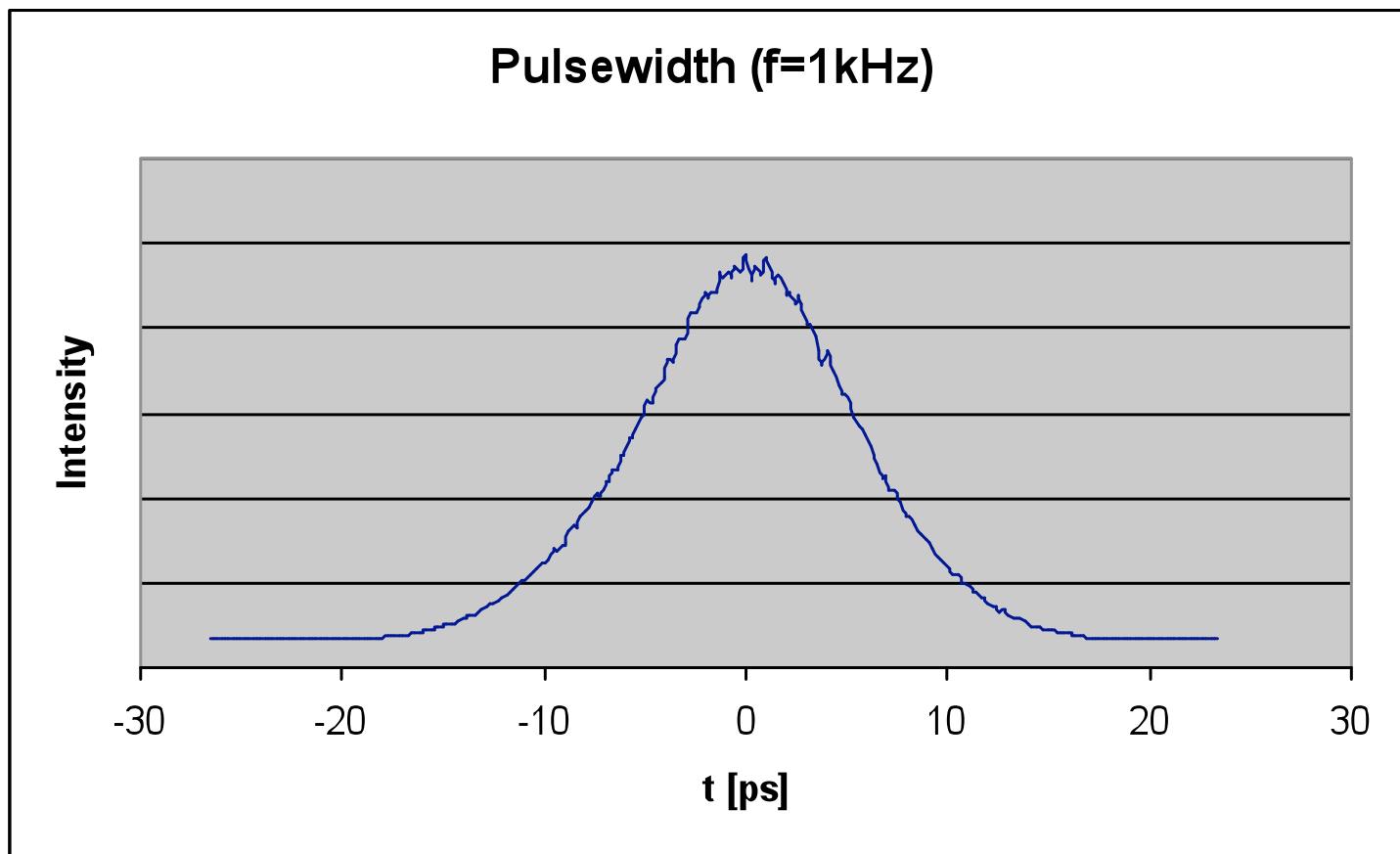
- **URDM** (User Replaceable DiodeModule)
- **Compactness**
- **Service friendly**
- **Reliable**

- **SEmiconductor Saturable Absorber Mirror**
- **Passive** ultra short puls generation
- **Selfstarting** (true turn key)
- **Excellence stability**

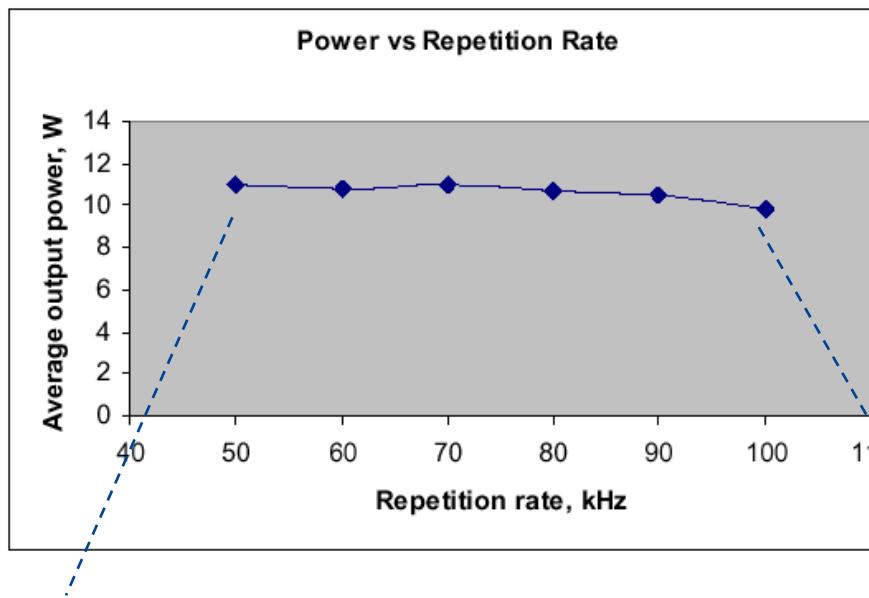


- **Compactness**
- **High Modularity**
- **User-Friendly & turn-key**
- **Multi-Watt output**
- **High temporal and spatial stability**
- **Sealed-off technology**
- **Single phase power supply**
- **RS 232 software remote control**
- **Low maintenance cost**

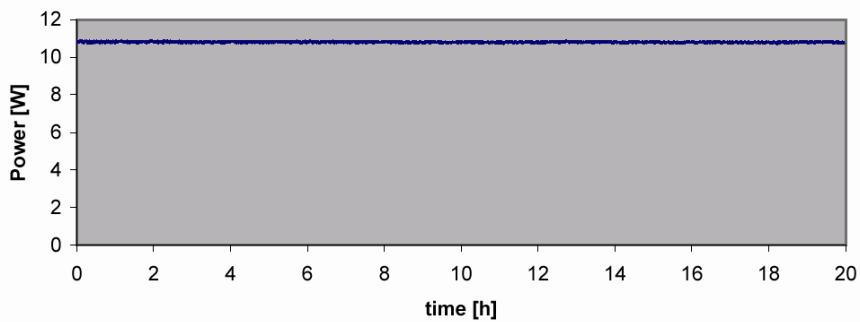




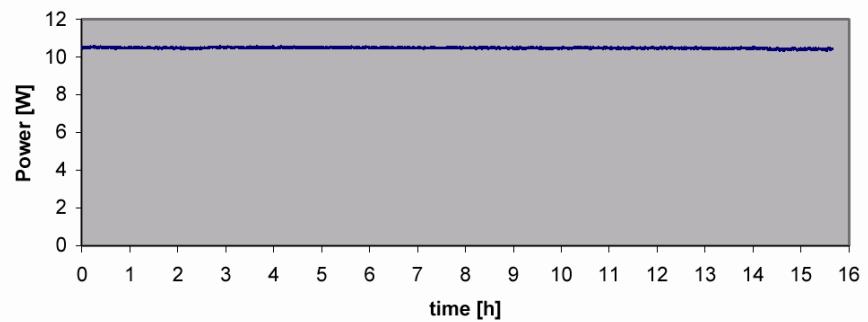
12.3 ps @ 1064 nm after Post Amp

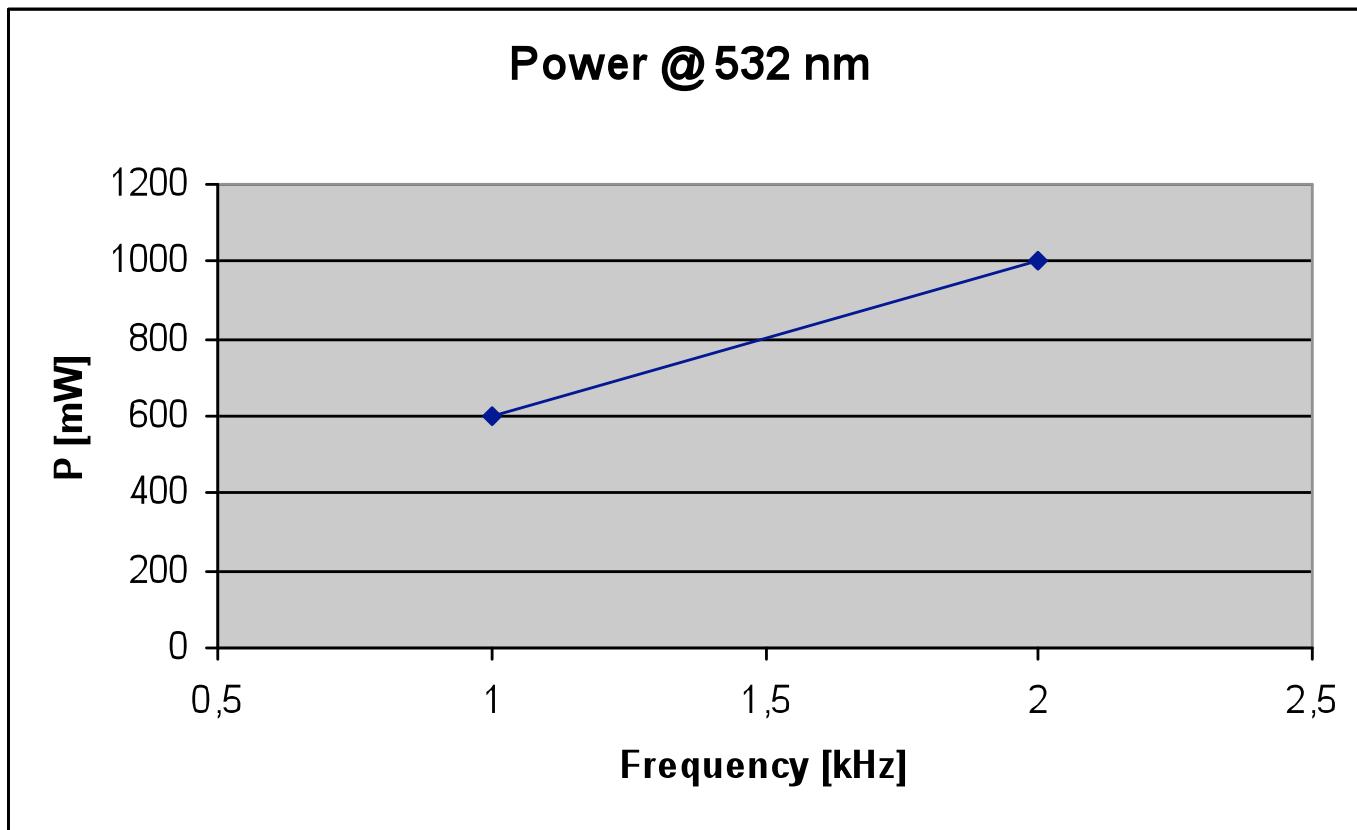


0.25% rms over 15 h @ 50 kHz

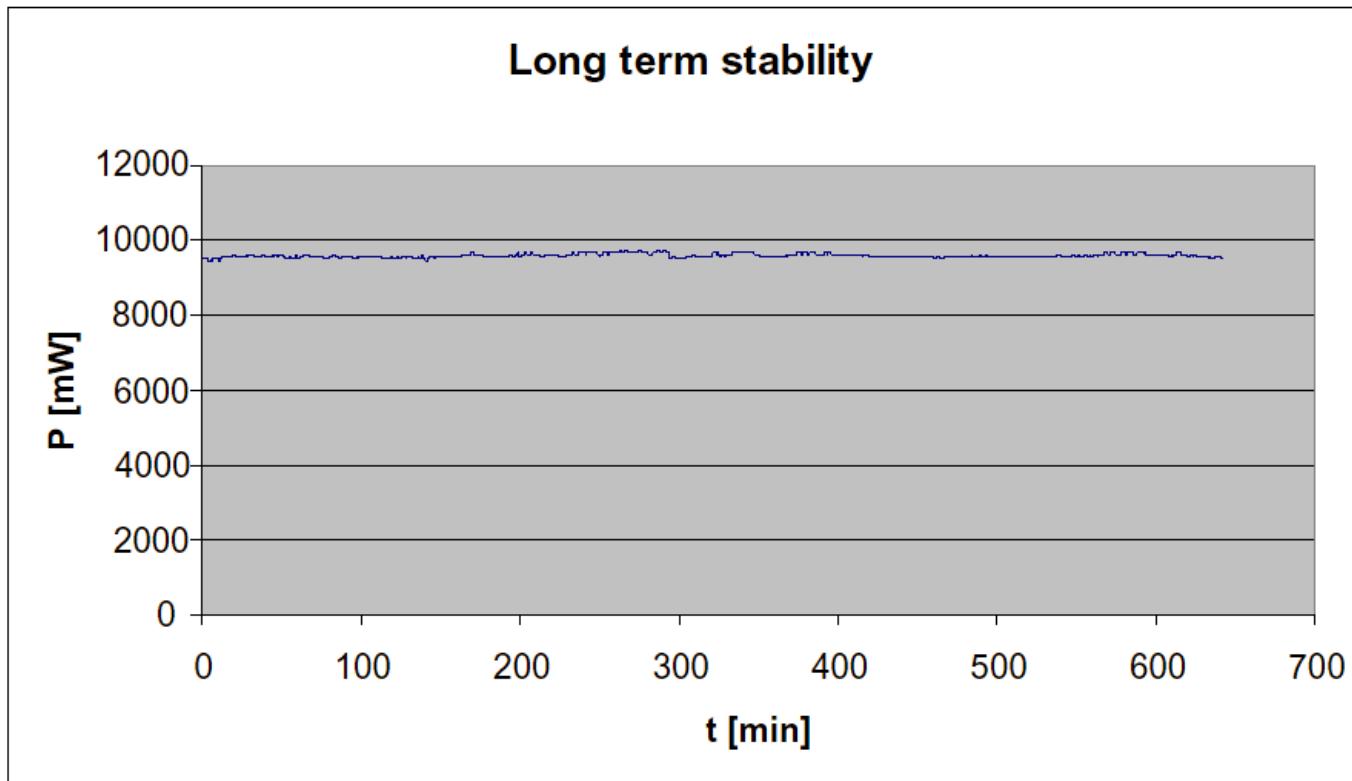


0.31% rms over 15 h @ 100 kHz



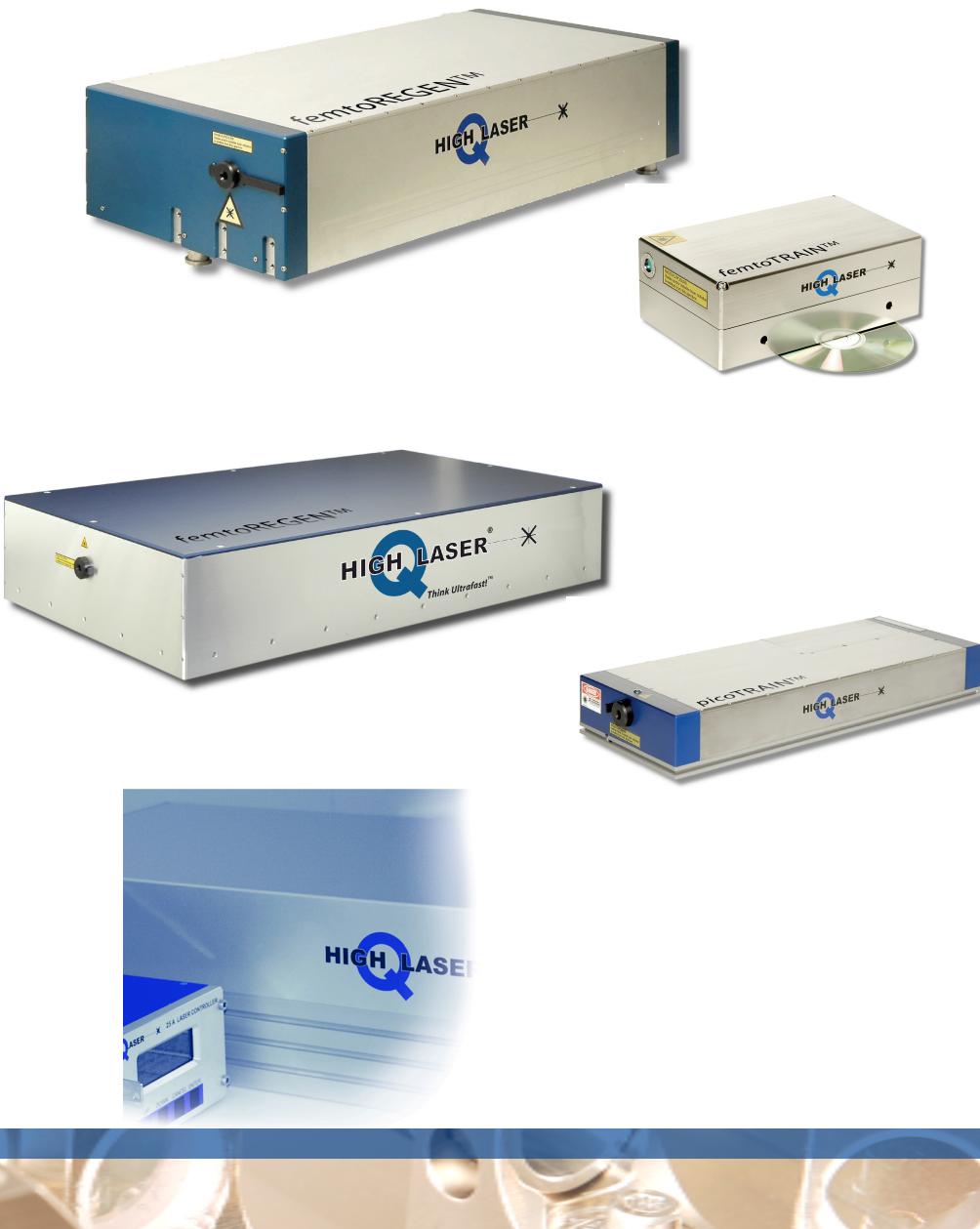


532 nm; diode pump current = const.



**1064 nm, P = 9,5 W @ 100 kHz,
Stability 0,5% RMS (643 min)**

- **UC-LASERS “INDUSTRIAL”**
compact | “ultra compact”
Industry compatible design
OEM compatible
sealed & closed laser, no access for user
- **SC-LASERS “SCIENCE”**
Scientific laser systems
based on bread board
flexible
user has access to the laser setup
- **Custom Laser System**
using our core technology
built at customer’s request



- **IC module is base for TRAIN series oscillator, Seeder, Regen or Post-Amp**
- **URDM technology**
- **Monolithic aluminum case**
 - massive solid structure
 - low vibration coupling
- **Thermal Management**
 - Liquid cooling in ground plate and URDM
 - high spatial and temporal stability
- **Industrial mirror mounts optimized by finite element method**
- **Sealed-off, manufactured in class 1000 clean room**
- **Compact, industry compatible OEM design**



- **REGEN SCIENCE packaging**

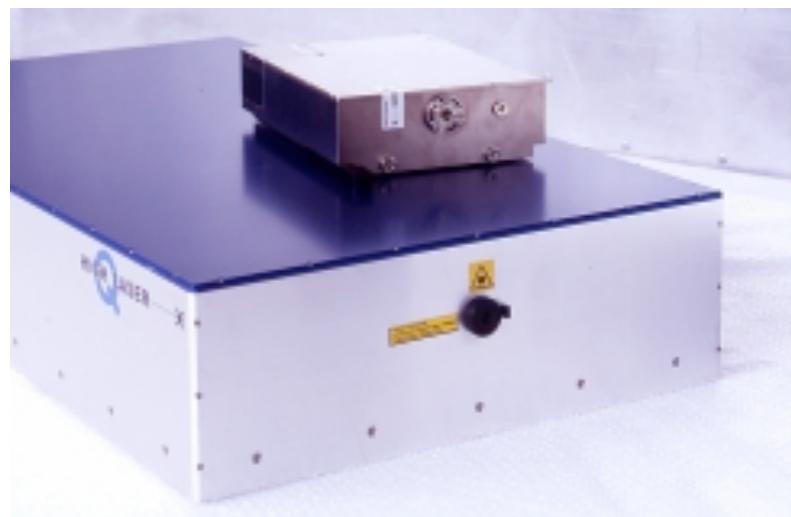
- 50 mm massive aluminum base plate
- thermally stabilized
- high vibration damping
- 4 to 6 IC modules in the one box
- Functional units are IC type, self-containing
- Few mirrors to guide the beam from module to module on the optical axis of the overall system
- Modules are field replaceable

- **UC Modules**

- UC module has one optical axis
- Monolithic aluminum case
- Thermal Management
- Sealed-off, maintenance free

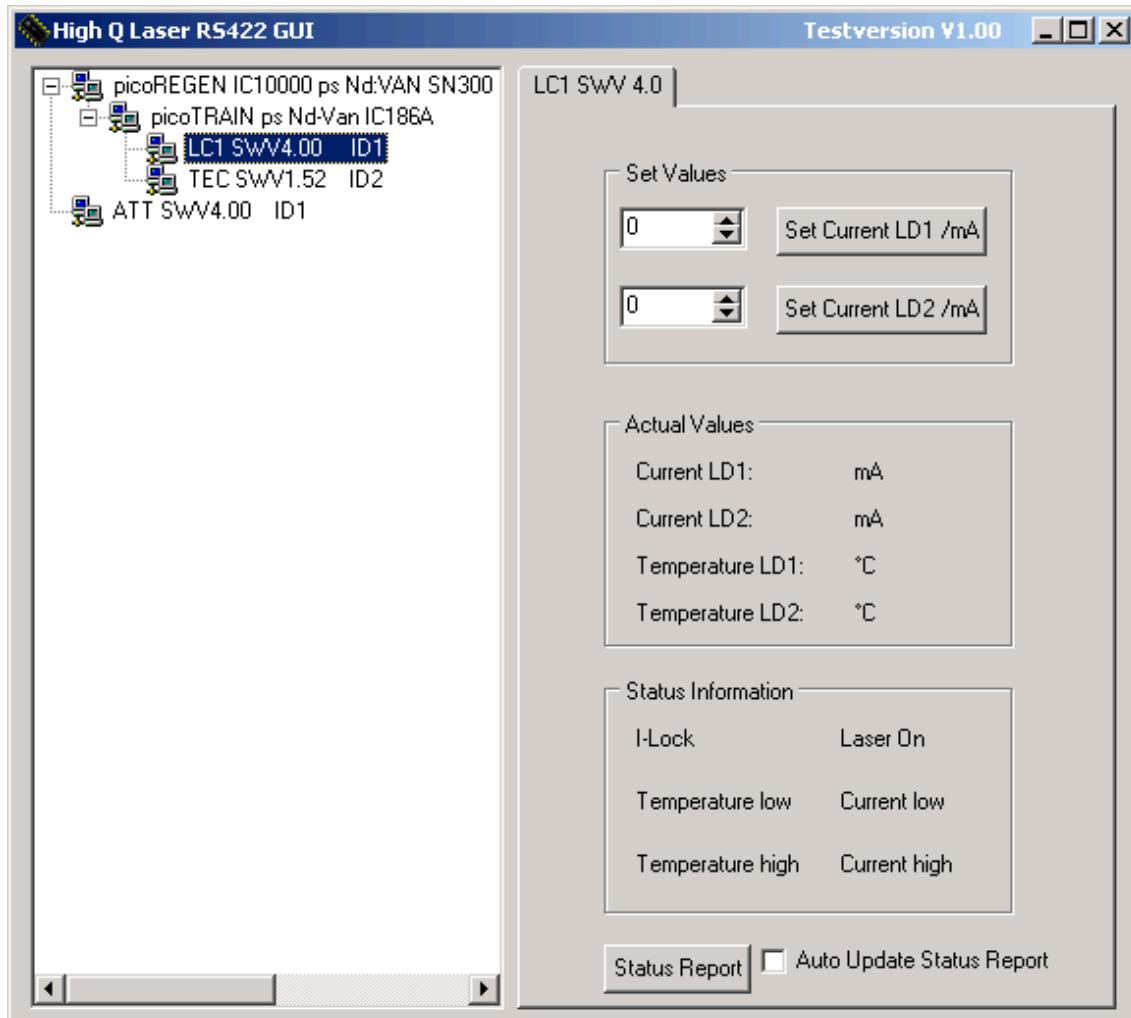
- **Simple and compact set-up for ultrafast amplifier**

- **Extreme short and long term stability including a recirculation chiller**

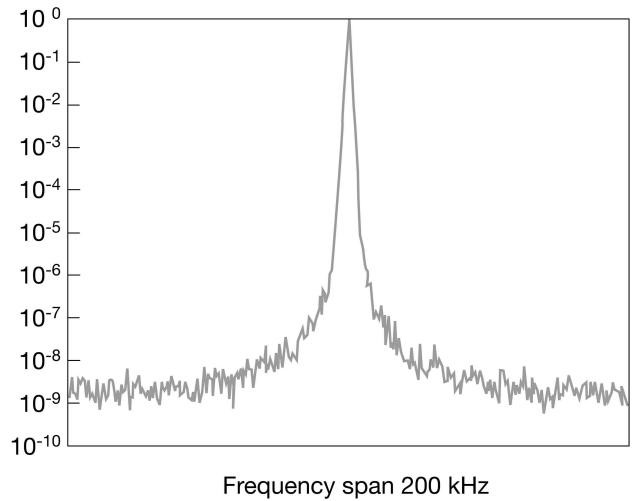
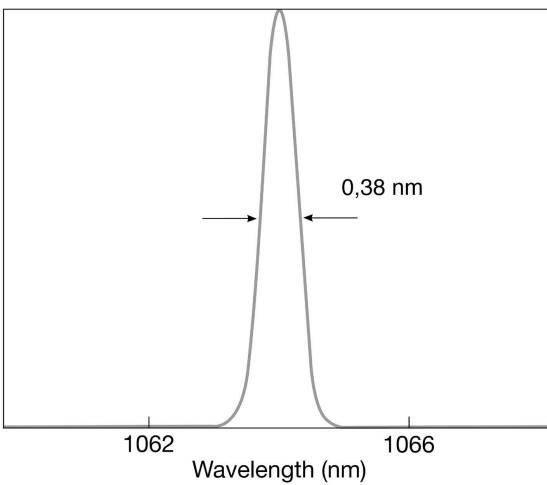
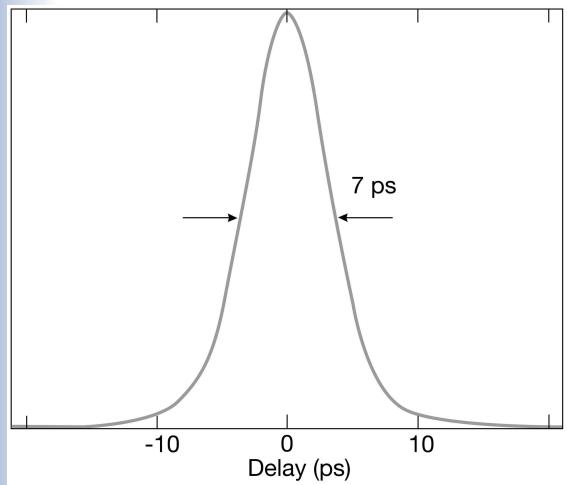


Industrial Control Software

- RS422 or RS232 remote control of all parameters
- GUI with status indication for overall remote control
- Error handling: Interlock activation
- Warning handling: User warning to finish current work piece, warning level can be defined by the user
- Status Report File containing all system parameters for remote maintenance and trouble shooting



picoTRAIN™ - Parameters

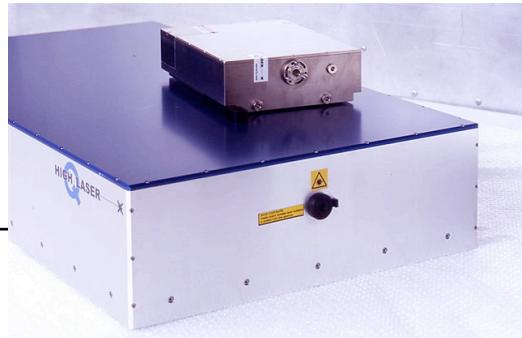
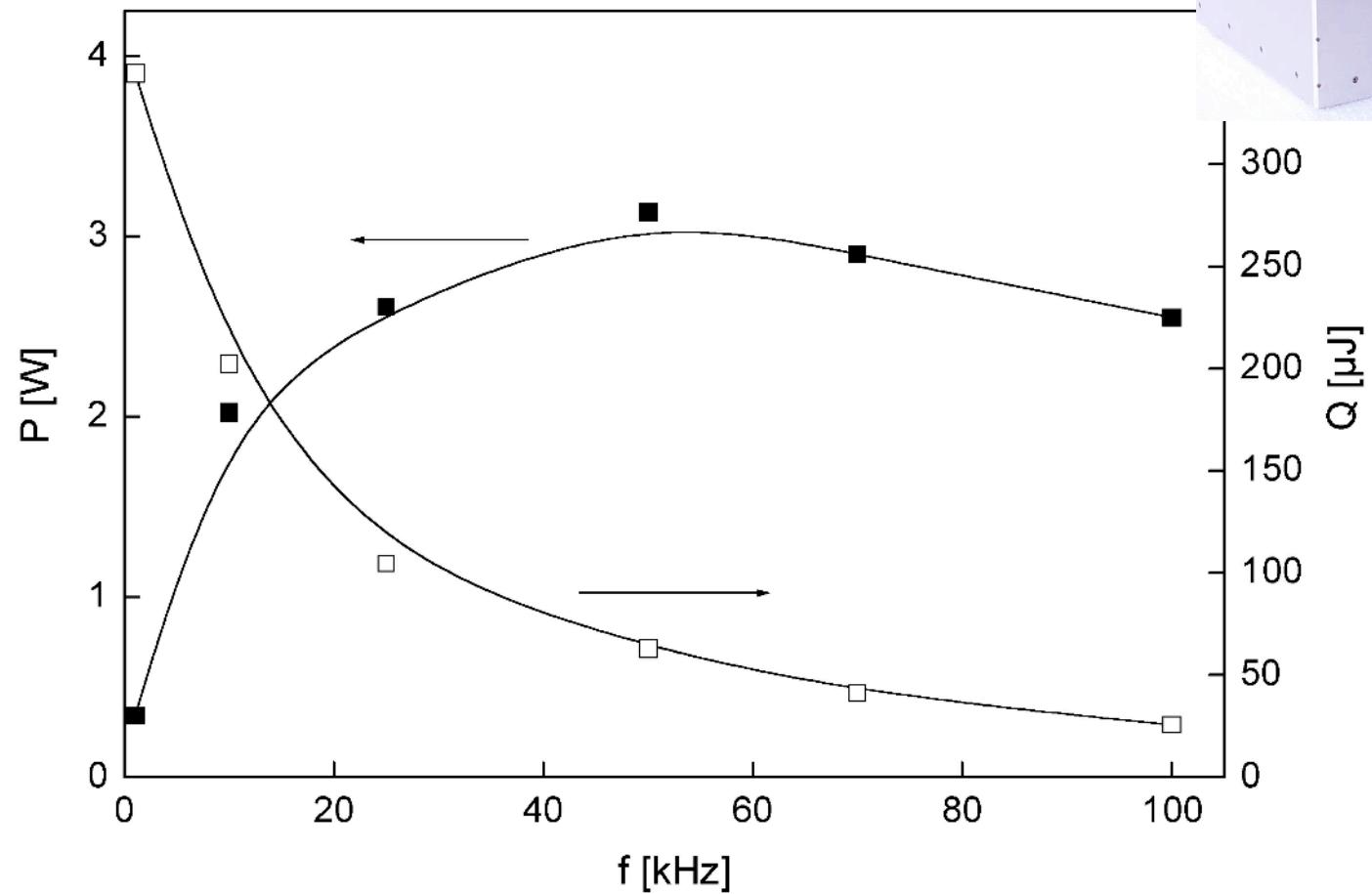


7 ps pulse width

0.4 nm spectrum

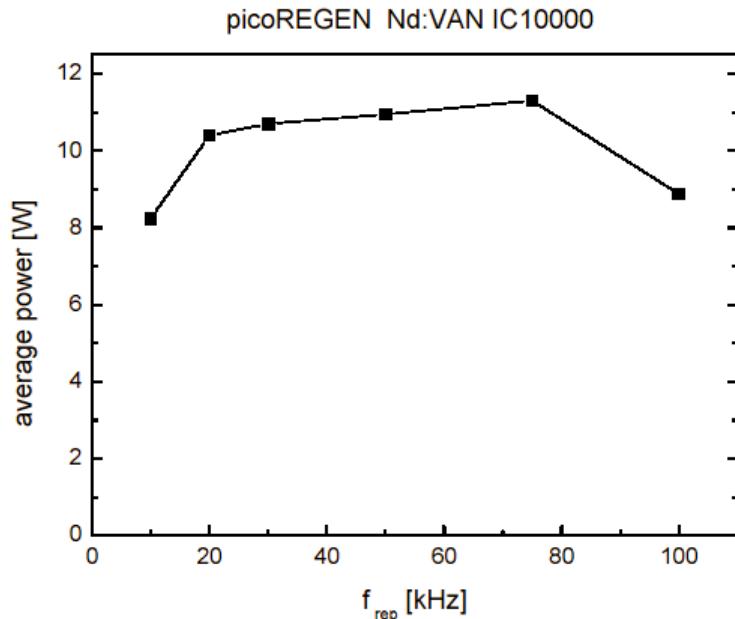
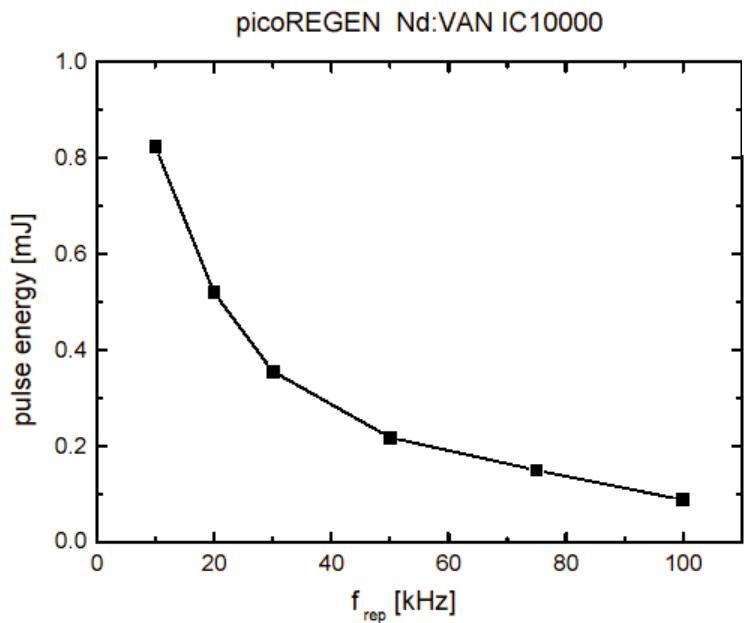
low noise

picoREGEN™ power / energy vs. reprise



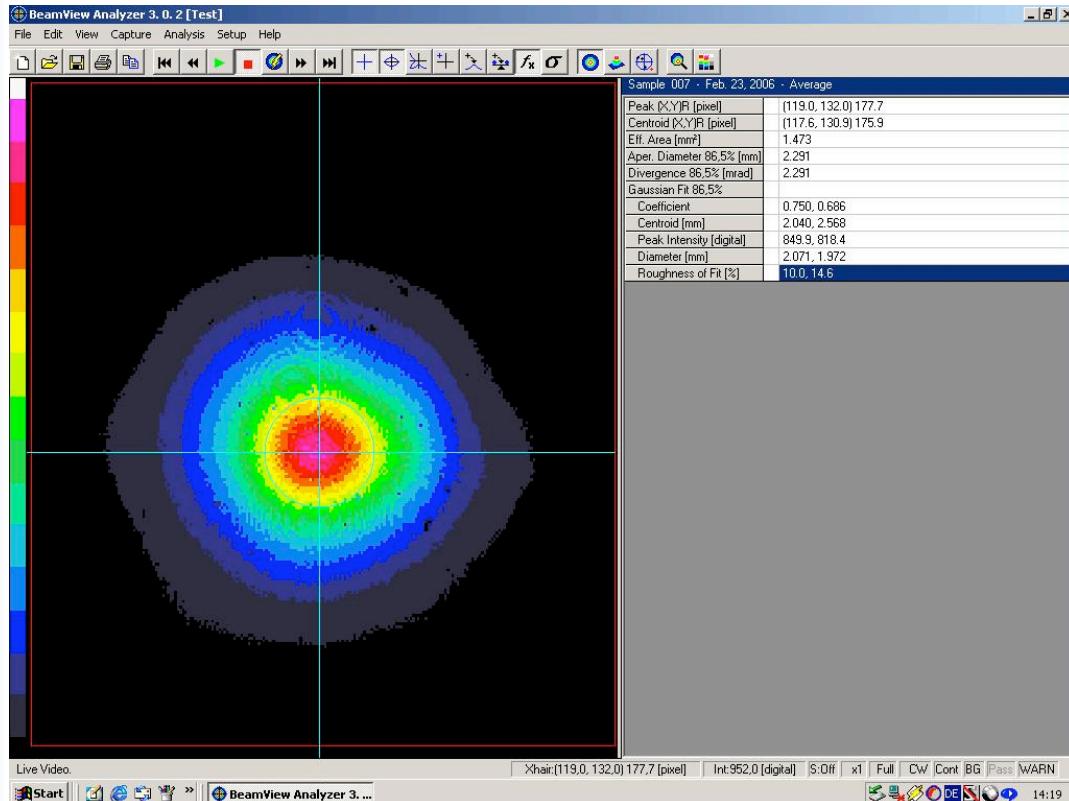
picoREGEN™ power/energy vs. reprise

up from 30 kHz constant power of ~ 10 W



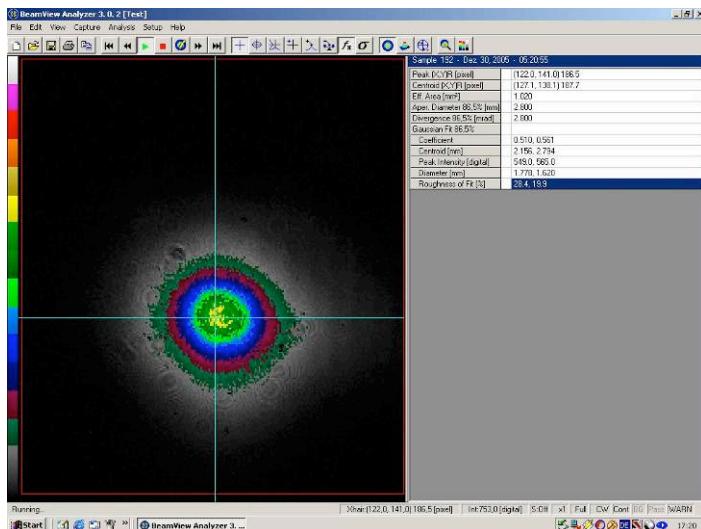
Pulse energy scales with
~ 1/Repetition rate

picoREGEN™ – THG Beam Profile

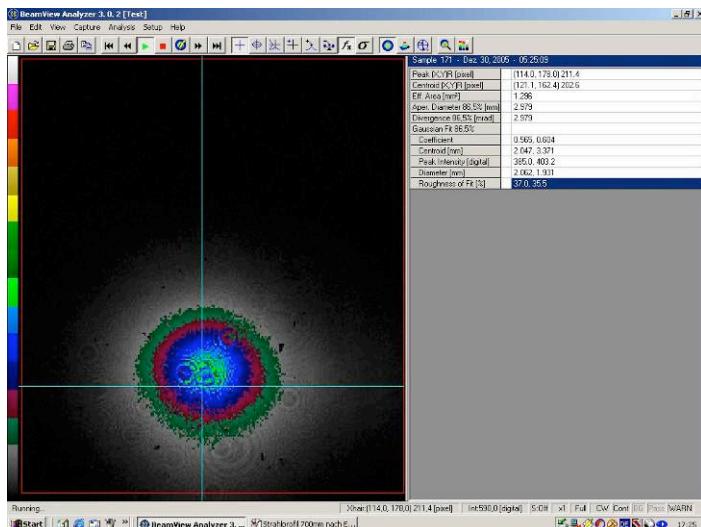


**1000 mm after laser exit
(355 nm)**

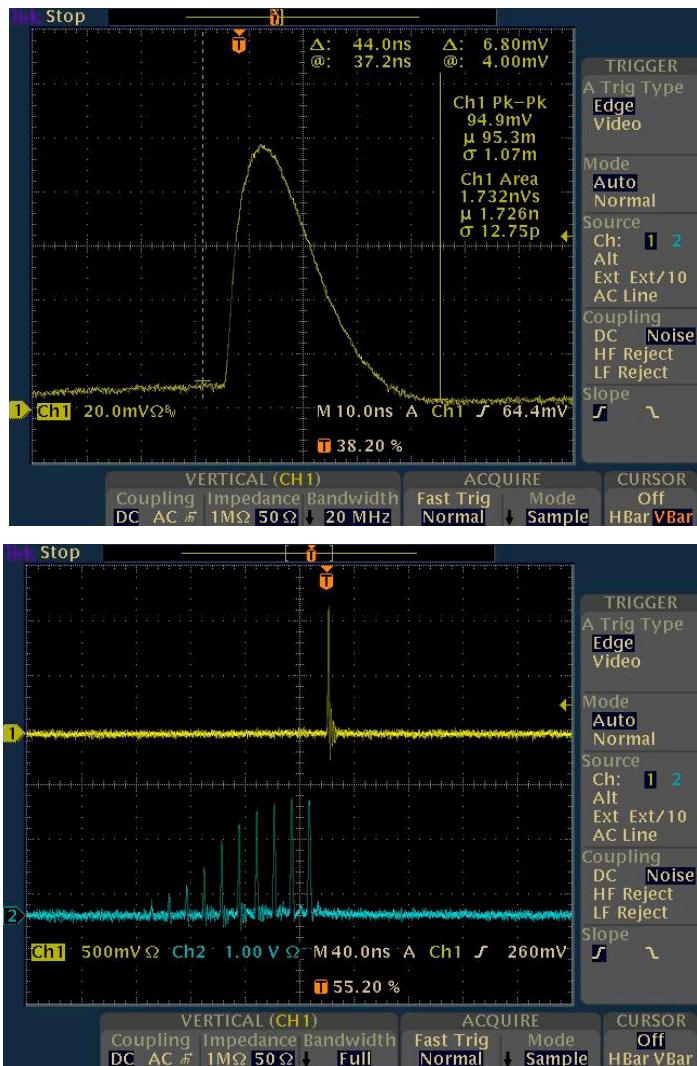
- X-Diameter 2.07 mm
- Y-Diameter 1.97 mm



- **700 mm after laser exit (262 nm)**
 - X-Diameter 1.78 mm
 - Y-Diameter 1.62 mm



- **1300 mm after exit (GREEN)**
 - X-Diameter 2.06 mm
 - Y-Diameter 1.93 mm
 - X-Divergence 0.47 mrad; full angle
 - Y-Divergence 0.52 mrad; full angle

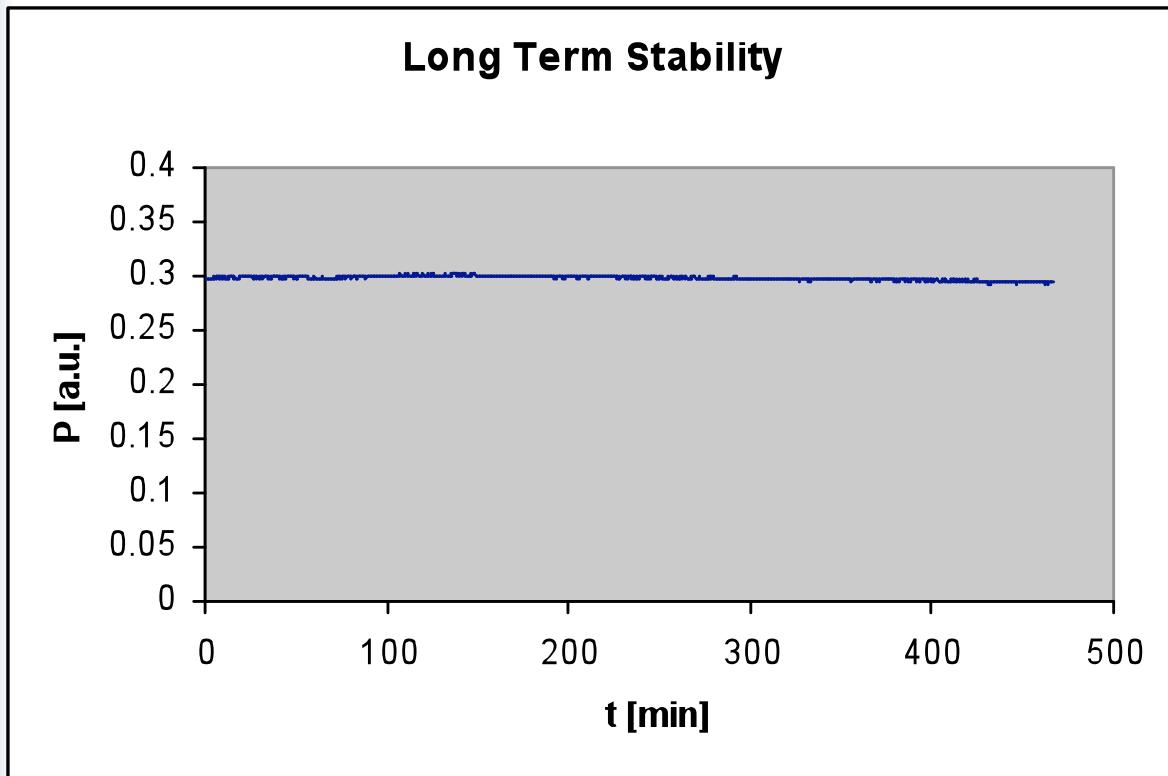


Pulse to pulse stability measurement

- Measured Standard Deviation: **1.1 %**
- Specified: < 3%

Pulse build up

- Out coupled pulse
- Last cavity roundtrips



Long Term stability measurement of FHG

- Measured Standard deviation **0.64 %**
- Specified: < 3.5 %

Comparison Packaging

High Q Laser system	Standard system
Industrial massive monolithic housing → high spatial and temporal stability, high vibration damping	Commercial “bread board” → “bi-metal” bending effect of “hot” upper plate against “cold” lower plate
Overall thermal stabilization	Local hot spots
Industrial mirror mounts optimized by finite element method with zero degrees of freedom → High Spatial Stability	Commercial mirror mounts → Spatial instability
Overall sealing off by o-rings: Sealed of housing, sealed URDM, diode entrance and beam exit → highest cleanliness and dust proofness → long term stability under “harsh” industrial environment	Bread board with metal sheet housing → dust penetration through slits and beam exit Made for temperature stabilized and “flow box” lab environment

Comparison System

High Q Laser	Standard system
<p>Industrial Compatibility and Regulations: Design according to ISO 10109 “Environmental Requirements” and ISO 9022 “Environmental Test Procedures”: Testing on shocks, vibrations, temperature transients, humidity</p> <p>System layout for 10 W <i>picoREGEN</i> 3 Stages: Seeder, RGEN, Post-Amp →high temporal and spatial beam stability</p> <p>Low maintenance cost URDM technology is cost efficient</p>	<p>Not available</p> <p>2 Stages for 10 W Picosecond amplifier only are border-line regarding thermal lensing →leading to instabilities</p> <p>High replacement cost for external pump diodes</p>

femtoREGEN™ UC-INDUSTRIAL

NEW
up to 8W for fast
Micro Processing



All-in-One Femtosecond Regenerative Amplifiers

Different UC-models

UC-1035-2000 2W
kHz, 20 µJ
UC-1040-8000 8 W
kHz, 16 µJ
→ TTL Trigger

s.p. - 200
s.p. - 500

femtoREGEN™ SCIENCE

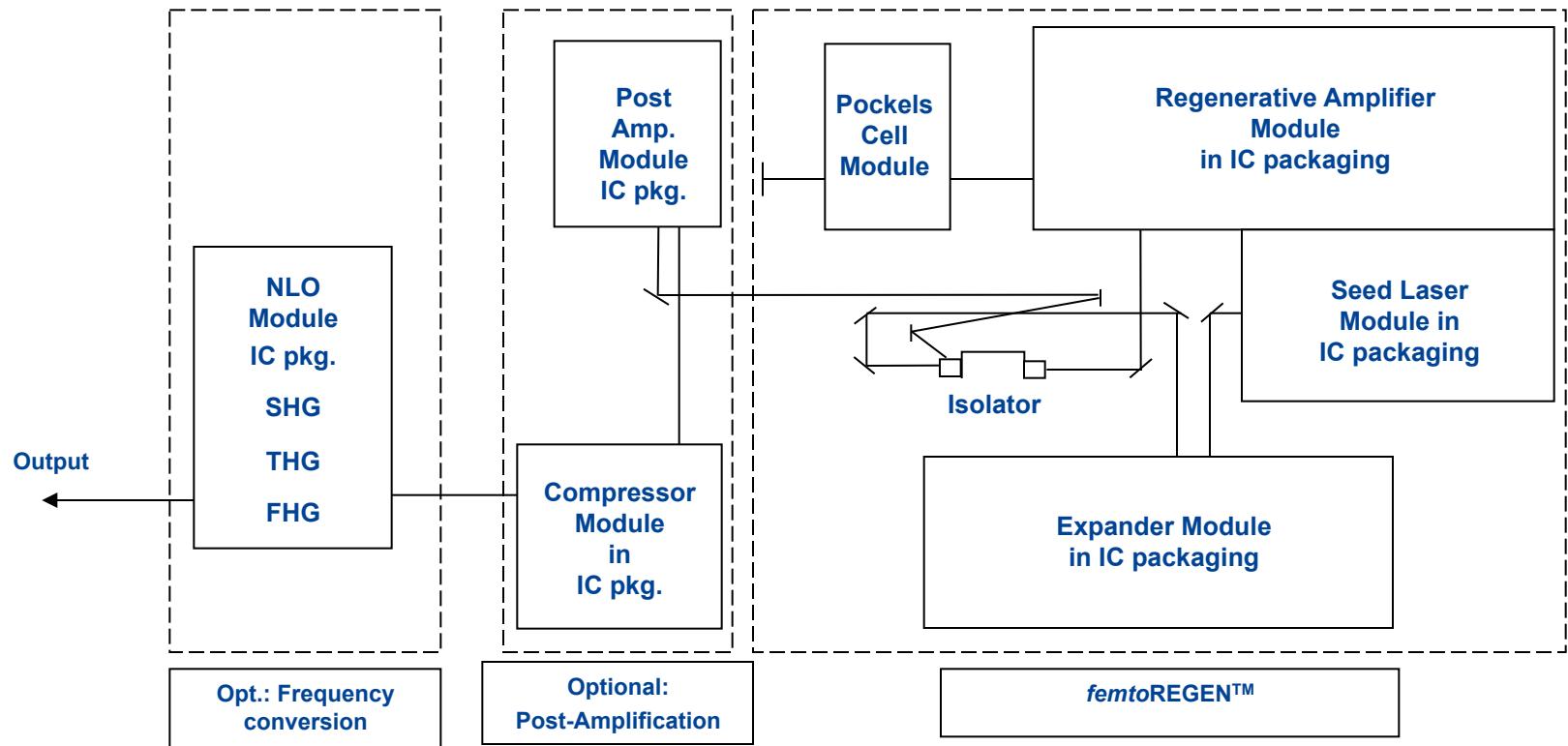


Different SCIENCE models

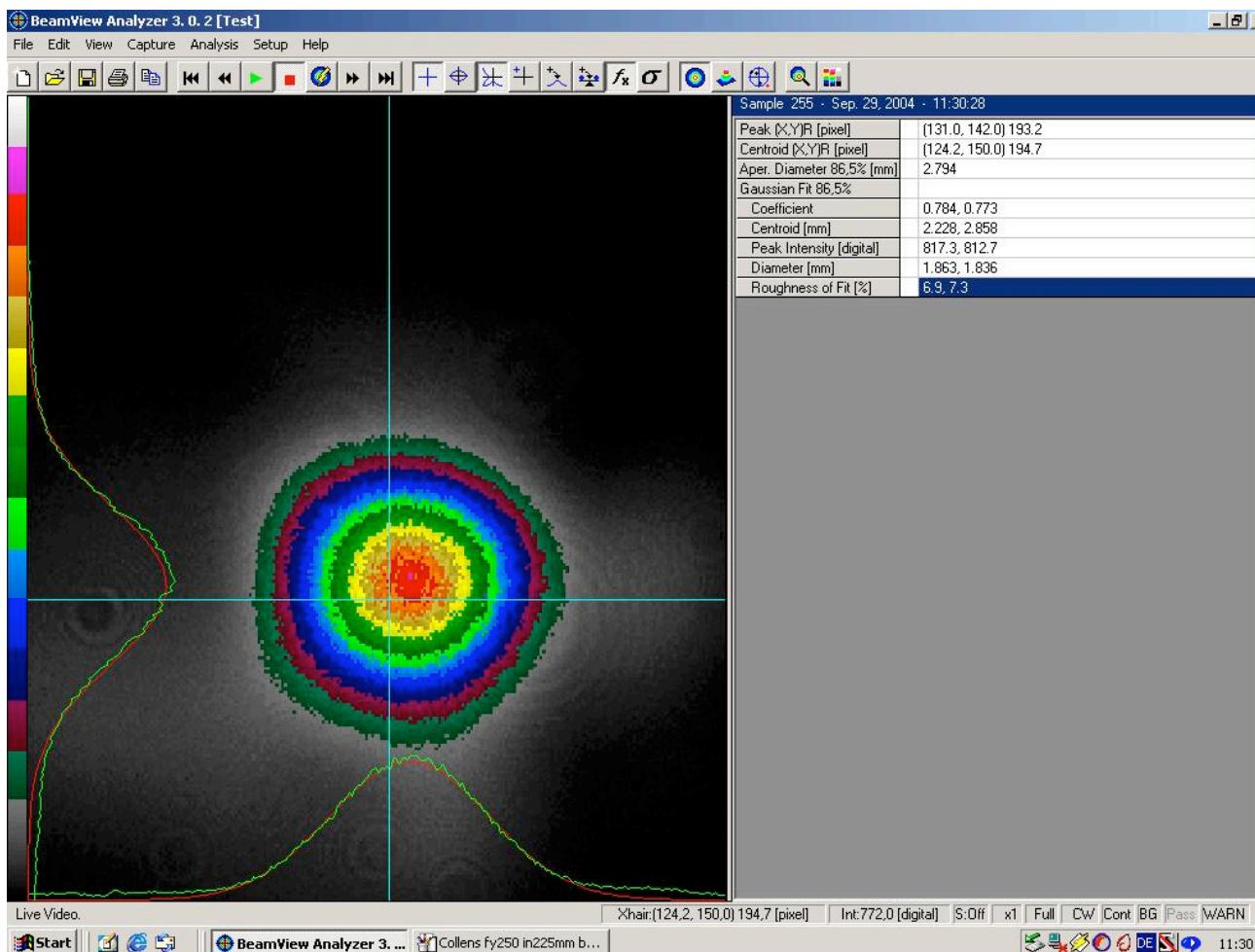
SC-1035-1000 HE Yb	1 kHz, 1 mJ;
SC-1035-1000 HEHR Yb	1 - 100 kHz, 0.4
mJ	
SC-1055-100 Nd:Glass	10Hz - 1 kHz, 1
mJ	
SC-1055-200 Nd:Glass	1 - 40 kHz, 5 µJ

femtoREGEN™ Series

Principal Optical Setup incl.
Options

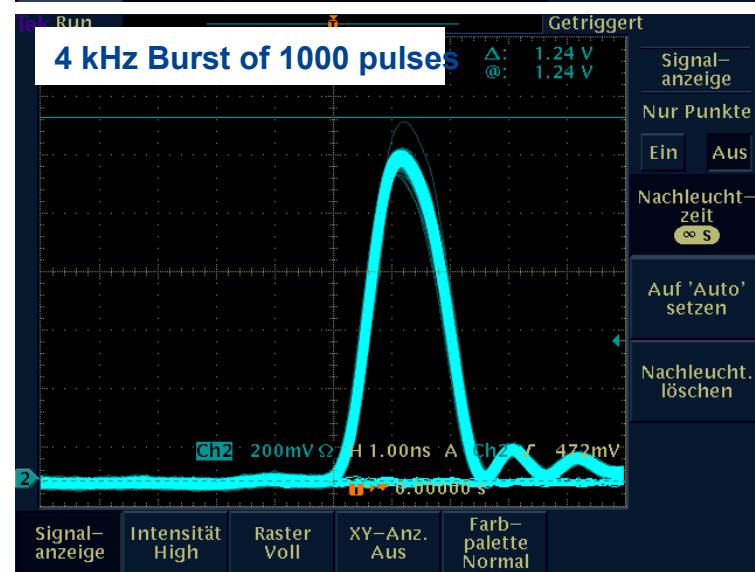
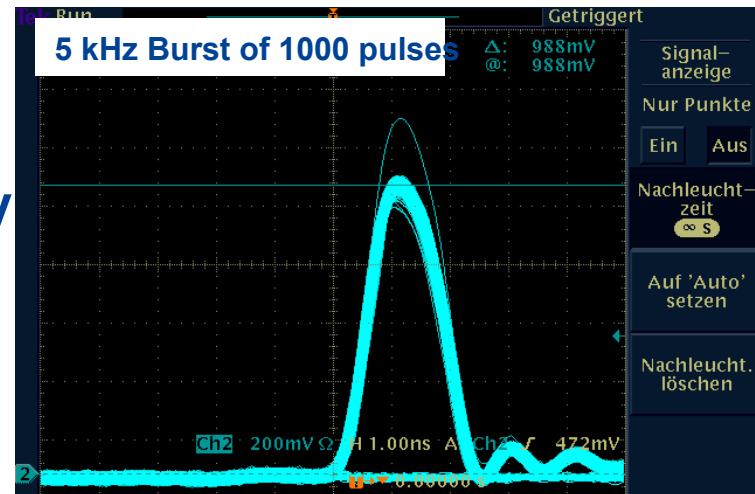


femtoREGEN™ beam profile



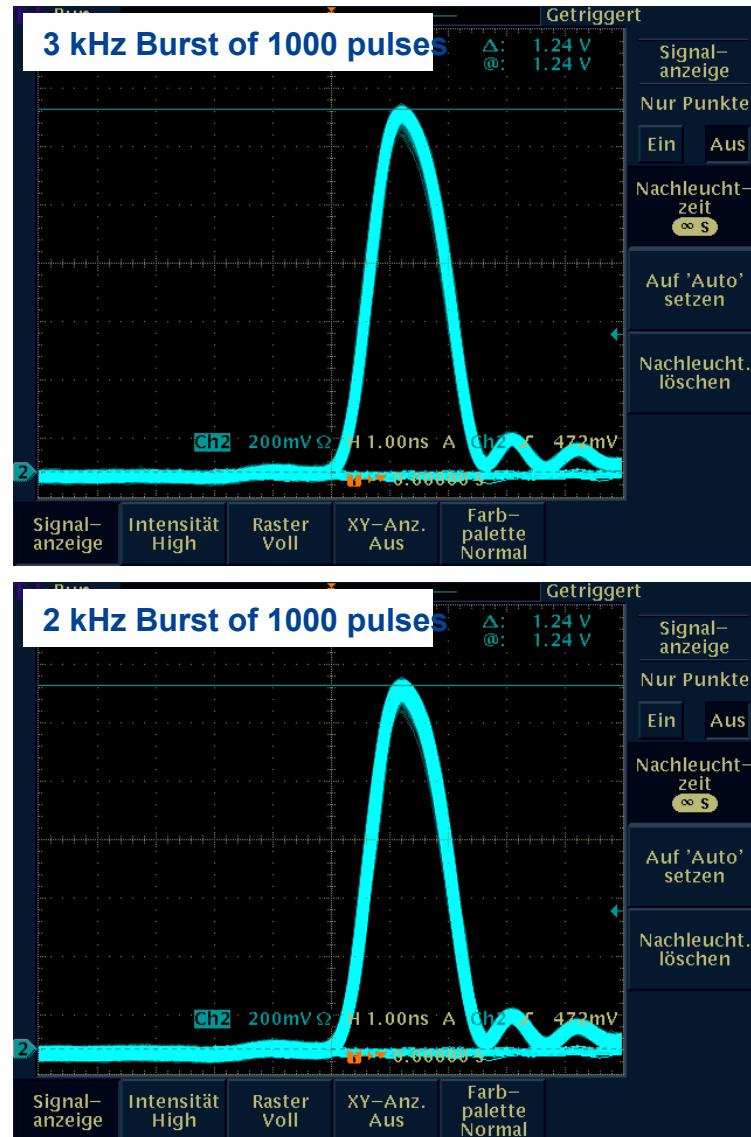
First Puls Excess Energy in Burst Mode

- 5 kHz Burst: 25% first pulse excess energy
- 4 kHz Burst: 20% first pulse excess energy

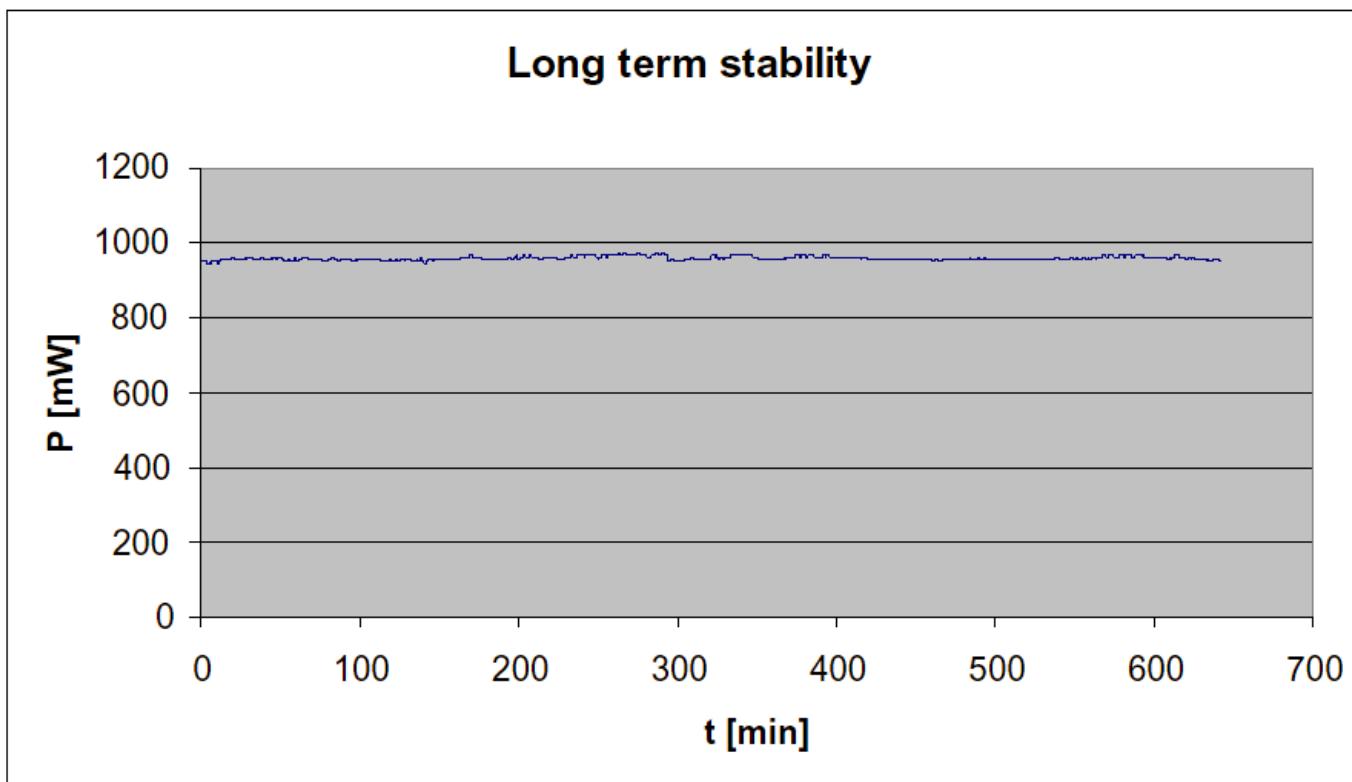


First Pulse Excess Energy in Burst Mode

- 3 kHz Burst: no excess energy → uniform pulse train
- 2 kHz Burst : no excess energy → uniform pulse train



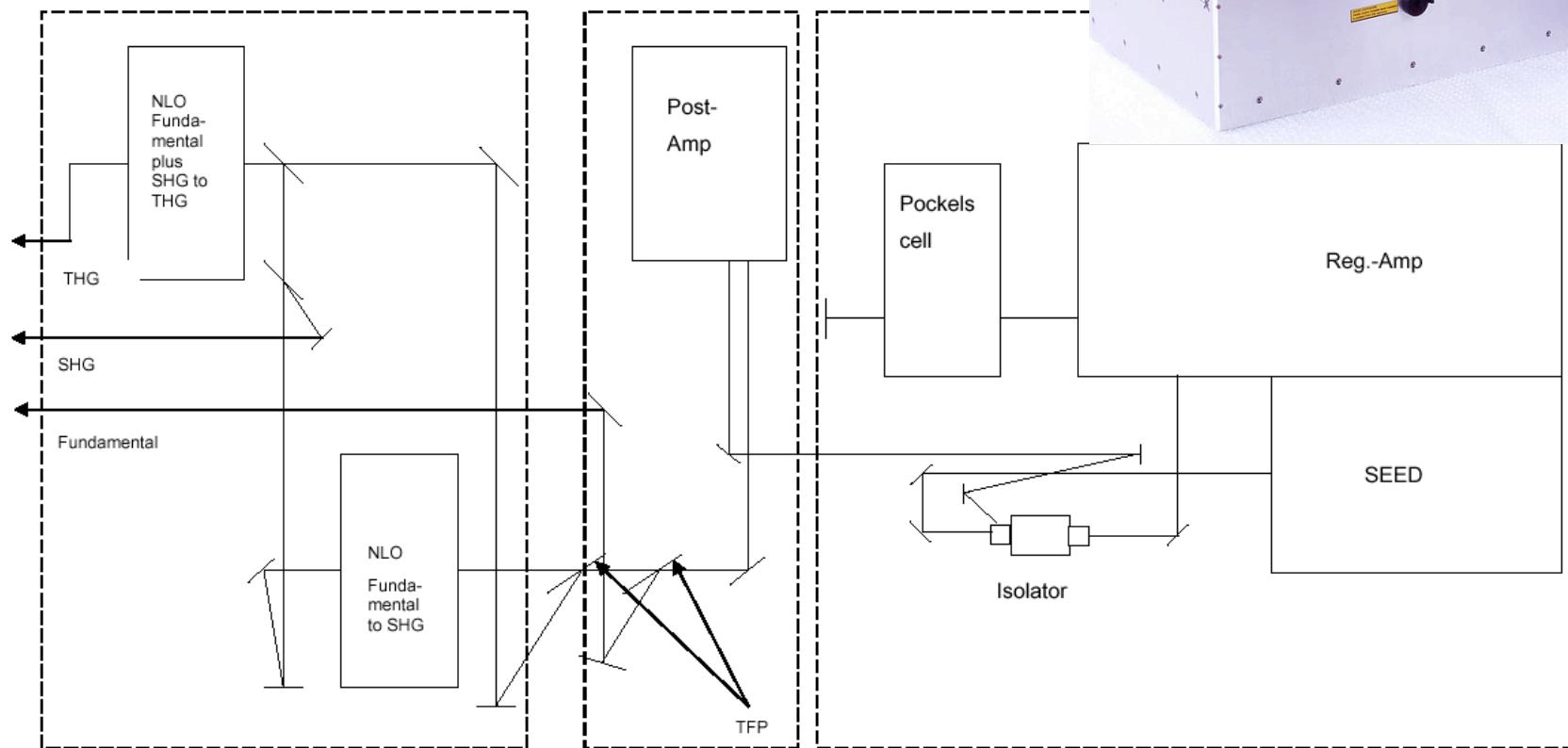
- Specifications of FHG
 - Efficiency: 15%, typical 20 %
 - Beam quality: $M^2 < 2$
 - Stability,
 - typical: < 3.5% (RMS), statistics over 1000 pulses
- SN 344: Actual FHG Performance
 - Efficiency: 23 %
 - Beam quality: $M^2 < 1.5$
 - Stability
 - Long term: < 0.6 % (RMS), 8 hours
 - Pulse to pulse: 1.1 %



*picoREGEN*TM Series

Principal Optical Setup incl.
Options

Pulse Picker



07/2004

Optional:
Frequency conversion

Optional:
Post-Amplification

*picoREGEN*TM
IC-1500 Nd:YLF REG AMP

Modular Concept – *picoREGEN™ SHG*

